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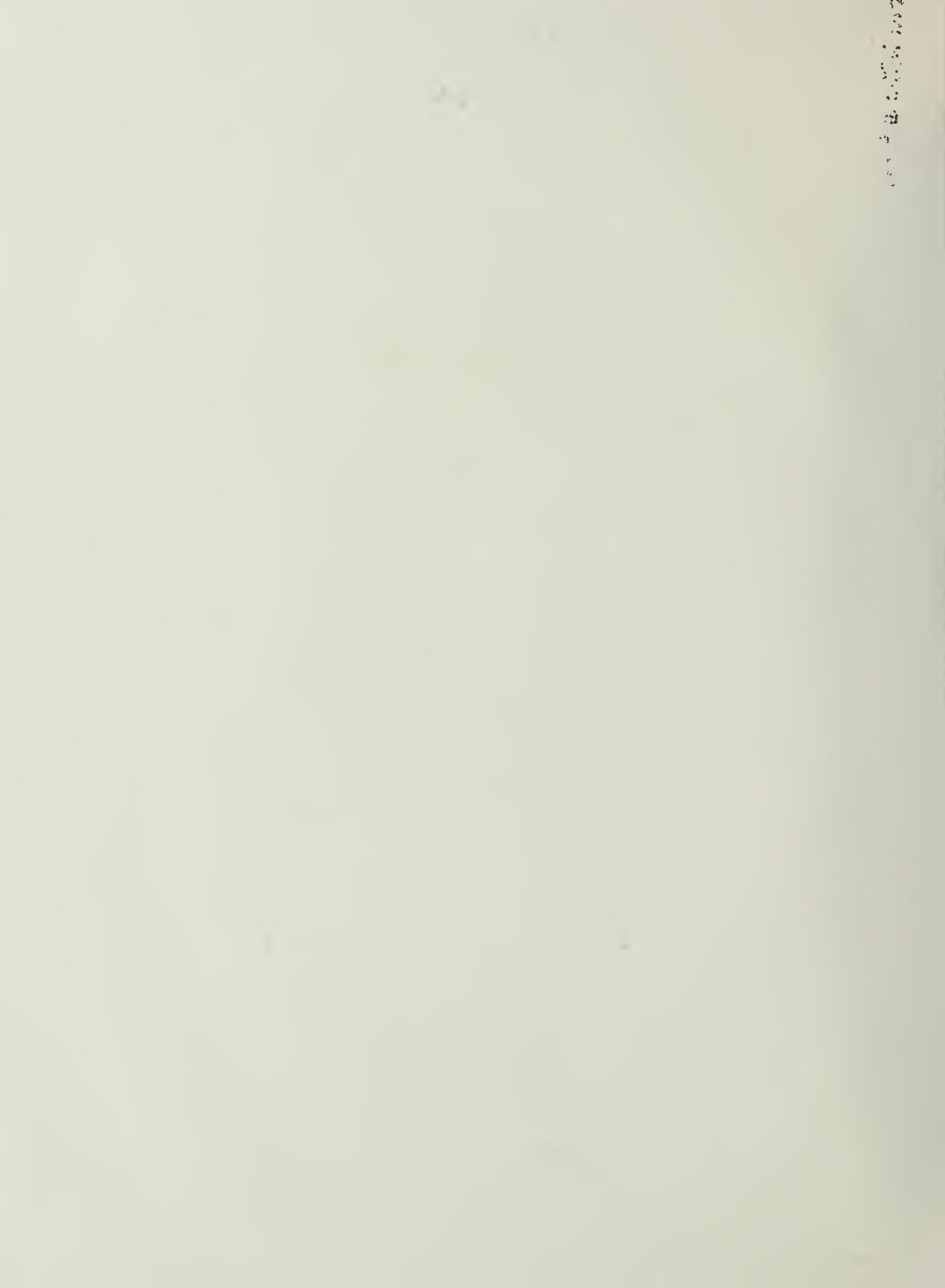


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EVALUATION OF HYDROCARBONS IN RUNOFF TO

// SAN FRANCISCO BAY
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December 1985

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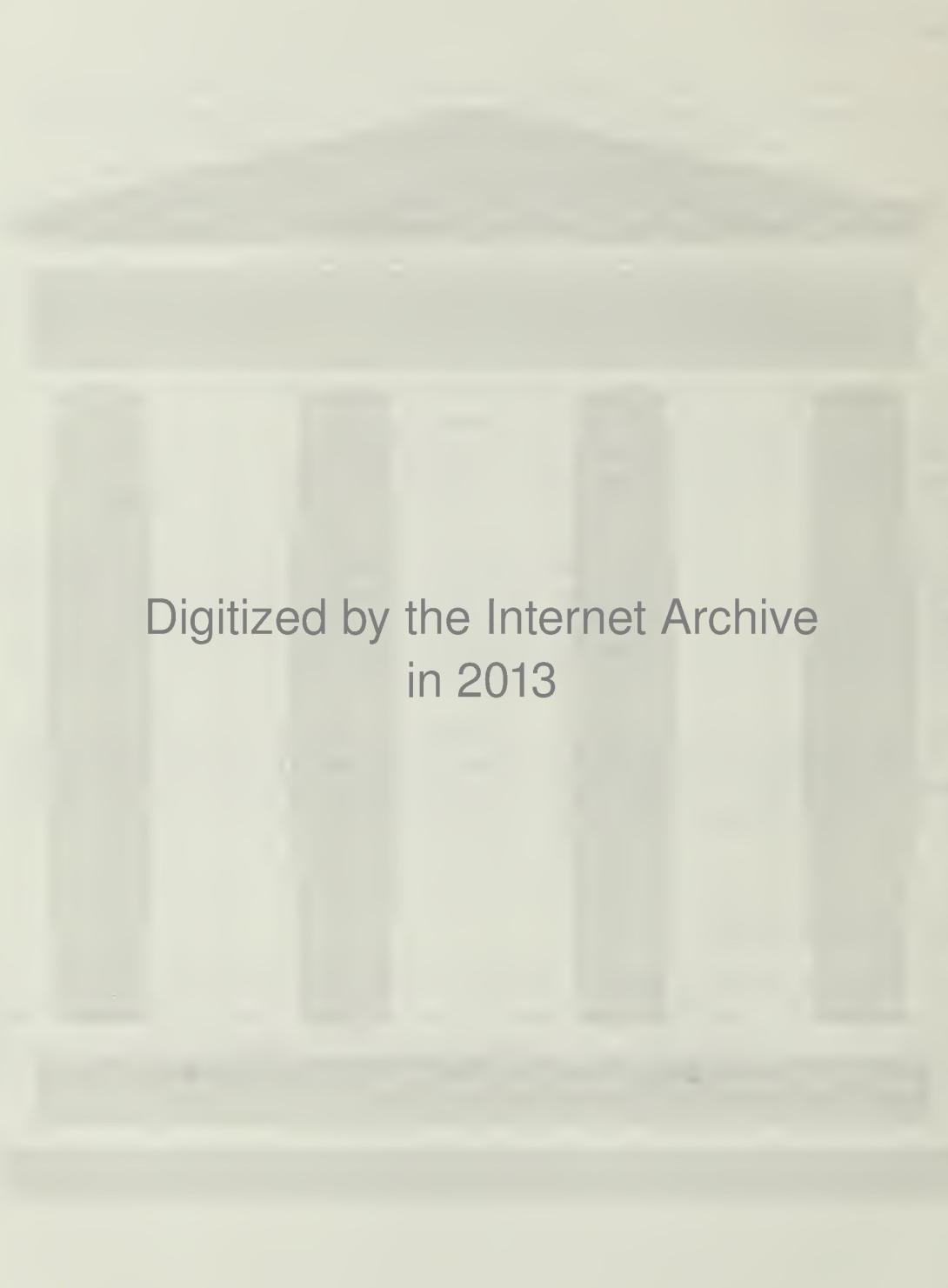
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TABLE OF CONTENTS

	<u>Page</u>
Table of Contents	i
List of Tables.	iii
List of Figures	v
Executive Summary	vii
 CHAPTER I - INTRODUCTION.	1
Objective	1
Background.	2
Approach.	8
Experimental Design.	8
Modelling.	9
Best Management Practices.	10
 CHAPTER II - ANALYTICAL AND FIELD METHODS	11
Introduction.	11
Methods Available to Evaluate Hydrocarbons.	12
Preliminary Separation	13
Extraction	14
Extract Evaluation	18
Technique Suitability for Routine Analysis.	25
Selected Methodology.	29
Technique Performance.	34
Conventional Pollutant Measurements	35
Field Program	36
 CHAPTER III - MODEL DEVELOPMENT	41
Introduction.	41
Model Description	41
Model Application	44
Calibration/Verification.	48
Sample Site Characterization.	50
 CHAPTER IV - ANALYTICAL RESULTS AND DISCUSSION.	59
Introduction.	59
Statistical Relationships	62
Storm Condition.	62
Land Use	64
Hydrocarbon Indicators	69
Qualitative Evaluation.	69
Aliphatic Hydrocarbons	69
Aromatic Hydrocarbons.	82
Polar Fractions.	86
Summary of Findings	87
 CHAPTER V - MODEL RESULTS	91
Introduction.	91
Calibration	92
Modelling Results	95
 CHAPTER VI - CONCLUSIONS AND RECOMMENDATIONS.	105
Introduction.	105
Analytical Technique.	105

TABLE OF CONTENTS - (Continued)

	<u>Page</u>
Sampling Results . . . . .	.106
Modelling Results . . . . .	.108
Best Management Practices . . . . .	.110
Recommendations for Implementation . . . . .	.123
Enforcement . . . . .	.126
REFERENCES . . . . .	.129
APPENDICES	
A: Listing of All Runoff Data	
B: Listing of Runoff Station Means and Summary Statistics	
C: Listing of POTW Data and Summary Statistics	

LIST OF TABLES

	<u>Page</u>
Table I-1. Oil and Grease Concentrations in Runoff from Richmond, California.	7
Table II-1. Summary of Hydrocarbon Analysis Techniques	26
Table II-2. Recoveries of Various Organics Using the Selected Procedure	34
Table II-3. Methods for Measuring Conventional Pollutants.	35
Table II-4. Sampling Schedule.	38
Table III-1. Precipitation Stations Used in ABMAC Model	46
Table III-2. Sampling Site Drainage Land Use.	51
Table IV-1. List of Variables and Abbreviations Used for Data Analysis.	60
Table IV-2. Mean Values and Summary Statistics for All Measured Parameters.	61
Table IV-3. Mean Water Quality Conditions As a Function of Storm Phase	62
Table IV-4. Statistical Test for Variance: Water Quality Parameters As a Function of Storm Phase.	63
Table IV-5. Statistical Test for Variance: Selected Hydrocarbon Fractions As a Function of Storm Phase.	64
Table IV-6. Statistical Test for Variance: Oil and Grease As a Function of Land Use (Storm Phase Is Treated As a Block)	65
Table IV-7. Percentage of Aliphatic Hydrocarbons to Aromatic Hydrocarbons.	66
Table IV-8. Statistical Test for Variance: Ratio of Aliphatic Hydrocarbons to Aromatic Hydrocarbons As a Function of Land Use.	66
Table IV-9. Statistical Test for Variance: The Ratio of TOC to Oil and Grease As a Function of Land Use.	67
Table IV-10. Statistical Test for Variance: The Ratio of Heavy Odd Numbered Aliphatic Hydrocarbons ($>C_{25}$) As a Function of Land Use	68
Table IV-11. Polynuclear Aromatic Hydrocarbons Tested For in Benzene Extracted Fraction.	86
Table IV-12. Polar Compounds Tentatively Identified by GC Retention Time Matches	87
Table V-1. ABMAC Model: Coefficients from Richmond, California	92
Table V-2. Results of Multiple Regression to Determine Best Oil and Grease Coefficients by Land Use	94
Table V-3. Results of Multiple Regression to Determine Best Oil and Grease Coefficients by Land Use (Setting Undeveloped = 0).	95
Table V-4. Total Oil and Grease Loading to San Francisco Bay from Local Runoff Considering Year 1985 Land Use . .	97
Table V-5. Total Oil and Grease Loading to San Francisco Bay from Local Runoff Considering Projected Year 2000 Land Use	97

LIST OF TABLES (Continued)**Page**

Table V-6.	Best Oil and Grease Coefficients by Land Use after Eliminating Outlying High Values (Setting Undeveloped = 0)	98
Table V-7.	Total Oil and Grease Loading to San Francisco Bay from Local Runoff Considering Year 1985 Land Use and Eliminating Outlying High Values	100
Table V-8.	Changes in Projected Land Use between Years 1985 and 2000 in the San Francisco Bay Area	100
Table V-9.	Total Oil and Grease Loading to San Francisco Bay from Local Runoff Comparing Projected Growth with Exclusive Growth of Commercial Area.	101
Table V-10.	Estimates of Point Source and Nonpoint Source Loading of Hydrocarbons to San Francisco Bay	103

LIST OF FIGURES

	<u>Page</u>
Figure II-1. Selected Analytical Procedure.	30
Figure II-2. Extraction Apparatus	32
Figure II-3. Sample Station Locations	37
 Figure III-1. Schematic Diagram of the ABMAC Model	43
Figure III-2. Local Drainage in San Francisco Bay.	45
 Figure IV-1. Chromatograph of Aliphatic Fraction from Used Motor Oil.	71
Figure IV-2. Chromatograph of Aliphatic Fraction of Freshly Extracted Diesel Fuel	72
Figure IV-3. Chromatograph of Aliphatic Fraction of Diesel Fuel After Overnight Aeration.	73
Figure IV-4. Chromatograph of Aliphatic Fraction from Fern Wax.	74
Figure IV-5. Chromatograph of Aliphatic Fraction from Elmhurst Creek Showing Atypical Heavy N-Alkane Series	75
Figure IV-6. Chromatograph of Aliphatic Fraction from Temescal Creek.	76
Figure IV-7. Chromatograph of Aliphatic Fraction from Elmhurst Creek.	77
Figure IV-8. Chromatograph of Aliphatic Fraction from Colma Creek	79
Figure IV-9. Chromatograph of Aliphatic Fraction from Sleepy Hollow Creek	80
Figure IV-10. Chromatograph of Aliphatic Fraction from Matadero Creek.	81
Figure IV-11. Chromatograph of Aromatic Fraction from Sleepy Hollow Creek	84
Figure IV-12. Chromatograph of Aromatic Fraction from Elmhurst Creek.	85
Figure IV-13. Chromatograph of Third Fraction from Elmhurst Creek.	88
 Figure V-1. Scattergram of Total Oil and Grease (Oil-T) in mg/l vs Land Use (Prcomm) in Percent for Storm Phase I.	99

EXECUTIVE SUMMARY

Significant quantities of petroleum derived organic pollutants enter San Francisco Bay from local drainage. Previous work indicates that this input may adversely effect the Bay's ecology. Measures to control this input have been hampered, in part, because of lack of information concerning the quantity and quality of these pollutants. This project was designed to answer some of these questions through a quantitative and qualitative investigation of extractable organic compounds in surface water runoff.

This study contains several distinct elements. Techniques were reviewed to determine means to quantify organic discharges better than currently done by oil and grease testing. From this review, a technique was developed offering potential for routine use. This technique was then used in a monitoring program from sites around the Bay Area representing a variety of land uses. Monitoring was also done for oil and grease from around the region, to model total loading to San Francisco Bay.

Following the analytical phase of research, Best Management Practices were reviewed. Recommendations were developed offering the best potential for controlling inputs into the Bay from local runoff.

The analytical technique selected for use was based on extracting specific hydrocarbon fractions through the use of several solvents. Since traditional oil and grease tests employ extraction, the use of several extraction steps would not impose an additional monitoring burden beyond the current abilities of most laboratories. Gas chromatography was used to analyze specific fractions; this was done to examine the nature of each fraction rather than to suggest its use for routine monitoring.

Evaluation of the monitoring data revealed considerable information about the nature of extractable organics in runoff:

- o Oil and grease concentrations decreased with decreasing flow following a storm. However, while concentration decreased, the composition of the material did not vary significantly.

- o Land use significantly influenced oil and grease concentration, although variation with time from an individual location was tremendous. Runoff from undeveloped watersheds routinely had relatively low oil and grease concentrations, while runoff from more developed watersheds had both high and low concentrations following no regular pattern.
- o The predominant sources of hydrocarbons remained relatively consistent regardless of land use. Automotive products were the largest identified constituent in runoff, even from undeveloped watersheds. However, a statistically significant greater proportion of aliphatic hydrocarbons was found in runoff from developed watersheds than from undeveloped watersheds.
- o Oil and grease was found to comprise more of the total organic carbon found in runoff from developed watersheds than from undeveloped watersheds. This was due to relatively more of the anthropogenic sources of oils in developed watersheds being measured by oil and grease tests, while the humic, biogenic sources from undeveloped watersheds were incorporated only in total organic carbon measurements. This difference in the ability of the two tests to detect organics from these sources may be useful as an indicator of watershed development.
- o No easily measured water quality parameter was found that would be useful in serving as an indicator of oil and grease concentrations in runoff.

The results of the analysis were used to model overall loading into San Francisco Bay. Between 5.3 and 9.9 million pounds of oil and grease were predicted to enter San Francisco Bay in a year with average rainfall from local runoff sources. Loading was predicted to increase in the next 15 years from 8 to 15 percent.

Control of commercial and industrial areas appears key to controlling overall loading to the Bay. The development of only 14,300 acres of land for commercial and industrial use, representing about 16 percent of the

total projected development in the local Bay drainage, was shown to account for 87 to over 98 percent of the predicted increase in loading.

Best Management Practices developed in earlier work looking at discharge from a single watershed in the Bay were reviewed to develop recommendations reflecting the current project results. Two non-structural control measures were considered to have the most promise for limiting input from major sources: (1) oil recycling, and (2) inspection as part of the air emission inspection and maintenance program. Examination of specific hydrocarbon fractions was recommended for investigative activities rather than routine monitoring.

Six structural control measures should be considered for controlling organics in runoff. The use of porous pavements or frequent cleaning of areas receiving heavy vehicle use have potential for removing pollutants before they enter the storm sewer. Similarly, the use of oil sorption systems or greenbelts can be used to capture pollutants running off of areas of high loading. In contrast, wetlands and dispersion devices can be used to protect sensitive areas near storm water discharges, serving as "end of pipe" protection of the Bay.

An effective enforcement program is key to controlling discharge into the Bay. Efforts are beginning at the Federal level to require additional controls on surface water runoff. Current regulation provides a basis for prohibiting discharges, but little practical ability to do so. Implementation of Best Management Practices would reduce the need for enforcement but cannot be depended on to eliminate this need entirely. A combination of increased enforcement activities and Best Management Practices appears to be the best way to protect the Bay from pollutants in local runoff. As demonstrated through the modelling activities in this study, the problem will continue to grow if action is not taken.

CHAPTER I

INTRODUCTION

OBJECTIVE

Local pollution sources may be responsible for significant quantities of hydrocarbons entering San Francisco Bay and adversely affecting its ecology. Evidence exists that biota in the Bay is in poor condition, and that hydrocarbons are found in elevated concentrations in animal tissue and in the water column (DiSalvo and Guard 1975, DiSalvo et al. 1976, Jung and Bowes 1980, Greenberg and Kopec 1985). While various researchers have suggested that hydrocarbons are responsible for some of the problems in the Bay, no direct cause/effect relationships have been found (Whipple et al. 1981). In fact, little work has been directed toward investigating these relationships.

Prerequisite to gaining an understanding of the effects of hydrocarbons is knowledge regarding the quantities and types of material entering the Bay. Previous work indicates that oil and grease concentrations in runoff from an urban watershed frequently are greater than that allowed for point source discharges (Stenstrom et al. 1982, 1984). Furthermore, a major fraction of total loading to the Bay of other pollutants, notably heavy metals, has been shown to originate from local runoff (Russell et al. 1981). Therefore, it is reasonable to conclude that hydrocarbons from runoff into the Bay are probably highly significant.

Complicating an assessment of hydrocarbon loading and impact are inadequacies in typical monitoring procedures. Hydrocarbons are commonly measured only as "oil and grease," with no differentiation between fractions. Oil and grease constitute a wide variety of compounds, including vegetable oils, animal fats, soaps, waxes, esters, petroleum products, fatty acids and any other hydrocarbons extractable from water with trichlorotrifluoroethane (freon), hexane, or similar solvents. The toxicity of these different compounds varies considerably, reflecting to some degree their origin.

In response to the threat posed by hydrocarbons, and the lack of a viable technique to monitor input, the experimental portion of this study was designed to fulfil two principal objectives. First, analytical techniques were developed to provide more information about the source of toxicity than offered by traditional oil and grease tests; these procedures were developed to be suitable for routine application. Second, samples were taken from watersheds reflecting a variety of conditions and land uses around the Bay to determine if differences in hydrocarbon constituents reflect land use and to model loading from all local runoff sources.

Study results were used to evaluate the necessity and feasibility of implementing control measures. Currently, increased efforts are underway on a national level to include storm water discharges as part of National Pollutant Discharge Elimination System (NPDES) permit programs. Key to these efforts are determinations if "a stormwater discharge is a significant contributor of pollution to the waters of the United States" (Federal Register, Vol. 49(188):38048, September 26, 1984). Best Management Practices (BMPs) are recommended that can be used to reduce hydrocarbons in runoff and meet regulatory demands.

BACKGROUND

Organic pollutants are receiving increasing attention as constituting a serious threat to water quality. Following the 1980 NPDES requirements, under section 402 of the Clean Water Act, point source dischargers are required to characterize their outfalls for a variety of organic pollutants, the specific testing requirements dependent upon the industrial category and the expected contaminants of the discharger (Federal Register, May 19, 1980). National drinking water standards have been established for a few specific organic pesticides and trihalomethanes under the Federal Drinking Water Act, and legislation is being developed which may greatly increase the number of regulated organic substances.

However, the 1972 Water Quality Control Plan for Ocean Waters of California (Ocean Plan) specified only a standard for total oil and grease (concentrations not to exceed 15 mg/l more than 10 percent of the time and not to exceed 10 mg/l more than 50 percent of the time). Specific standards were not identified for hydrocarbon or hydrocarbon groups other than total chlorinated hydrocarbons (not to exceed 0.004 mg/l more than 10 percent of the time and not to exceed 0.002 mg/l more than 50 percent of the time) and phenolic compounds (not to exceed 1.0 mg/l more than 10 percent of the time and not to exceed 0.5 mg/l more than 50 percent of the time). The 1978 revision of the Ocean Plan relaxed the oil and grease discharge standards considerably (concentrations not to exceed: 25 mg/l on a monthly average; 40 mg/l on a weekly average; or 75 mg/l at any given time) without delineating specific hydrocarbon groups. These oil and grease standards were not changed in the latest (1983) revision to the Plan. The 1974 requirements following the Water Quality Control Policy for the Enclosed Bays and Estuaries of California only specifically limited effluent such that "the discharge of oil and materials of petroleum origin in sufficient quantities to be visible and/or in violation of waste discharge requirements shall be prohibited." The California State Regional Water Quality Control Board, San Francisco Region (RWQCB), in determining effluent limitations for point source dischargers into San Francisco Bay under NPDES regulations, generally has allowed oil and grease effluent concentrations near 1972 Ocean Plan levels of approximately 15 mg/l (R. Witsel, Chief of Planning, California State Regional Water Quality Control Board, San Francisco Region, 1981, personal communications).

While the historic focus on discharge control has been on industrial and municipal effluents, increased efforts are currently underway to control stormwater discharges from industrial and urbanized areas. While it is not clear how this control program will be implemented, a key consideration will be the potential impact of discharges on receiving water quality. Guidelines currently are not available to make a determination of the significance of stormwater discharges, or describing practices to effectively reduce pollutant loading.

Ideally, standards should, at least in part, be based upon the levels of contamination that will result in detrimental effects upon the exposed organisms. However, the data base concerning hydrocarbon toxicity and sub-lethal effect levels is very limited and inconclusive. Neff et al. (1976), who tested polynuclear aromatic hydrocarbons (PAH) compounds on the polychaete Neanthes arenaceodentata and the shrimp Palaemonetes pagio, found minimum levels of PAH toxicity at approximately 0.3 mg/l. The United States Environmental Protection Agency (U.S. EPA) lists PAH as a water quality criteria pollutant under section 304 of the Clean Water Act, although recognizing that the lack of information precludes an accurate determination of hazardous concentration levels (U.S. EPA 1980a).

Applying their "Guidelines" for deriving water quality criteria (Federal Register, November 28, 1980) the U.S. EPA indicates that acute toxicity will result to certain marine aquatic species at concentrations of 0.3 mg/l, with indications of lower levels of toxicity to particularly sensitive species. Furthermore, the criteria document suggests that consumption of aquatic organisms containing 311 mg/l, 31.1 mg/l or 3.11 mg/l PAH may result in an incremental lifetime increase of cancer risk of 10^{-5} , 10^{-6} , and 10^{-7} , respectively. Since the lifetime carcinogenicity risk is the probability that a person would get cancer sometime in his or her life, this document suggests that consumption of organisms containing 31.1 mg/l mg/l PAH may result in one additional incidence of cancer in a population of one million. The World Health Organization, in its European Standards for Drinking Water, recommends a PAH standard of 200 ng/l based on a composite analysis for fluoranthene, benzo (a) pyrene, benzo (g,h,i) perylene, benzo (b) fluoranthene and ideno (1,3 - cd) pyrene (U.S. EPA, 1980a).

The toxicity of several mono-aromatic components contained in oil and grease have been studied by various researchers and/or has been included in the U.S. EPA list of criteria pollutants. Ethylbenzene appears to be the most toxic of the mono-aromatics tested. The U.S. EPA criteria document on ethylbenzene indicates possible acute toxicity in saltwater aquatic life at concentrations at least as low as 0.43 mg/l (U.S. EPA 1980b). Benville and Korn (1977) found that the 96-hour LD50 of ethylbenzene to shrimp (Crago franciscorun) was 0.500 mg/l. Whipple, et al. (1981), citing

various bioassay studies, suggest that acute toxicity of mono-aromatics to fish range from about 2.0 to 300 mg/l.

Unfortunately, very little testing of sub-lethal effect levels of PAH or mono-aromatics has been reported. However, using the assumption that critical sublethal pollutant concentrations are approximately two orders of magnitude lower than lethal concentrations for a given species (Anderson, 1979), estimates of safe exposure levels can be generated for PAH and ethylbenzene of 0.003 mg/l and 0.004 mg/l respectively. However, The U.S. EPA criteria document on benzene (U.S. EPA 1980c), another potentially important mono-aromatic pollutant, indicates critical chronic exposure levels at 0.700 mg/l, with toxic exposure a 5.100 mg/l, only about an order of magnitude difference between the chronic and toxic levels. Thus, 0.003 mg/l may represent a low estimate of the chronic effect level for ethylbenzene but lack of data precludes a more accurate estimation of critical levels at this time. A factor of 100 is a fairly arbitrary assessment of the difference between toxic and chronic toxicity levels, with no direct evidence of applicability for the entire spectrum of hydrocarbons (Wolfe et al. 1979).

To further complicate an assessment of toxicity in the environment is the ability of many organisms to accumulate hydrocarbons in their tissue. Bivalves tend to slowly and constantly accumulate hydrocarbons while fish and shrimp accumulate hydrocarbons more rapidly, reaching maximum levels within a few hours (Anderson 1979). Accumulation of aromatic hydrocarbons in tissues of marine animals appears to be somewhat dependent on partitioning of the hydrocarbon between the exposure water and the tissue lipids (Neff et al. 1976). The U.S. EPA has ranked priority pollutants based on the partition coefficient of a compound between water and an organic solvent. The organic solvent is representative of a fat-like material, thus providing a basis for an estimate of the extent to which a chemical will accumulate in an organism's fatty tissue. Several of the PAH and mono-aromatic compounds have been included in this ranking and show a relatively high affinity for bioaccumulation.

It is very difficult to compare the results between various toxicity studies because of the wide variation of commonly used techniques and materials. To make accurate assessments of the potential impact of pollutant exposure, it is critical to determine the sensitivity of the individual life stages of a species. Difficulties also arise in extrapolating laboratory data to the organism's native environment since laboratory techniques usually employ organisms specifically selected for their adaptability to laboratory conditions. Thus, critical exposure levels suggested by the U.S. EPA and from various studies do not conclusively indicate levels of safe exposure to pollutants in the native environment; care must be taken and field examinations conducted to determine if laboratory derived data is truly applicable to an exposed community.

Runoff sampled in 1979 from a watershed in Richmond (Contra Costa County) discharging into the Bay frequently had oil and grease concentrations exceeding 15 mg/l, with commercial parking areas and streets particularly high in hydrocarbon levels (Table I-1) (Stenstrom et al. 1982, 1984). Using these results to model Bay loading as a function of land use indicated that effective control could be accomplished by focusing on relatively small areas in the watershed and that future growth could result in dramatic increases in oil and grease discharge. While specific components of the oil and grease in the runoff were not identified, these relatively high levels indicate that non-point sources of hydrocarbons may be an important source of pollution to San Francisco Bay. Chromatography of oil and grease in the runoff indicated that automobile oil drippings and exhaust were important sources of petroleum hydrocarbons. Several other studies have shown the presence of toxic hydrocarbon compounds in stormwater runoff, including mono-aromatics and polynuclear aromatics (PAH) (Eganhouse et al. 1981, Mackenzie and Hunter 1979, Wakeham 1977). Finding relatively high levels of oil and grease in stormwater supports the position that significant amounts of toxic hydrocarbons may be entering San Francisco Bay, inadequately quantified by a measurement of the total oil and grease load.

Table I-1. Oil and Grease Concentrations in Runoff from Richmond,
California (Stenstrom et al. 1982, 1984)

Station Site Description	Area Land Uses	n ^a	Mean	Std.	90% Confidence Interval of Mean
1 Mouth of Water- shed	Composite of all uses in the watershed	56	7.57	11.56	5.00 10.14
2 Safeway Distri- bution Center	77% industrial property and parking; 23% impervious non- auto	58	7.16	5.07	6.04 8.27
3 Parking Lot	100% large scale commercial property and parking	59	15.25	12.02	12.64 17.86
4 Street Near Service Station	70% residential; 30% small-scale commercial property and parking	59	10.80	6.00	9.50 12.10
5 Upstream Residential Area	90% residential; 5% undeveloped	59	4.13	5.24	2.99 5.26

a. n = number of observations

APPROACH

This study has several distinct elements. Methodology was developed to examine hydrocarbons in runoff, and to determine the significance of various organic fractions. This methodology was used as part of a sampling program examining runoff from diverse watersheds in the San Francisco Bay Area. Oil and grease input into San Francisco Bay was modelled using sampling results for calibration. Recommendations were made for Best Management Practices to reduce oil and grease in urban runoff based on the empirical findings and modelling results.

EXPERIMENTAL DESIGN

The sampling program was developed to accomplish three objectives:

- o Determine appropriate coefficients for use in modeling oil and grease loading as a function of land use.
- o Determine if differences exist in the composition of hydrocarbons found in runoff as a function of land use.
- o Determine the suitability of various measurements in serving as indicators of hydrocarbon pollution in urban runoff.

Grab samples were taken at widely scattered stations throughout the San Francisco Bay Area. Samples from all stations were routinely analyzed for Oil and Grease, Turbidity, Total Organic Carbon (TOC), Total Dissolved Solids (TDS) and Total Suspended Solids (TSS). This program allows the evaluation of these measures as possible indicators of oil and grease levels. This also generated substantial data from which to calibrate the model in determining appropriate coefficients to assign as characteristic of specific land uses.

Samples were also taken to analyze for specific hydrocarbon fractions. A major element of the study was to design and use an analytical method

offering more information about toxicity and origin than traditional oil and grease tests, while retaining utility for routine application. During each sampling run, samples were taken from selected stations for this analysis. These stations were chosen to determine if significant qualitative, as well as quantitative, differences occur as a function of land use.

Analytical and field methods are described in Chapter II. Also included in this chapter is a review of available techniques for evaluating hydrocarbons in water and a discussion of why the selected method was chosen. A description of the results of data analysis is presented in Chapter IV.

MODELLING

A simulation model (Association of Bay Area Governments Macroscopic Planning Model) was used to estimate hydrocarbon loading from local runoff into San Francisco Bay and predict anticipated changes due to development and implementation of Best Management Practices. The model is based upon relationships between rainfall, runoff, and pollutant concentrations as functions of land use. Thus, required input data are amount of rainfall, land area devoted to various land uses, and quality and runoff coefficients characteristic of each land use.

Data obtained in the sampling program were used to determine appropriate oil and grease coefficients. Land use data were obtained from census information and census projections (ABAG 1985). Rainfall/runoff coefficients were obtained from previous work from a single watershed in the San Francisco Bay Area (Stenstrom et al. 1982, 1984). The model is described in Chapter III, including a description of the methods used to obtain input data. Chapter V contains the results of the modelling, as well as a description of how the empirical data obtained from sampling were incorporated into the model.

BEST MANAGEMENT PRACTICES

Previous work (Stenstrom et al. 1982, 1984) has indicated Best Management Practices that have substantial potential for reducing oil and grease loading into San Francisco Bay. With the work from this current study, recommendations are made in Chapter VI regarding the need for implementing these practices.

CHAPTER II

ANALYTICAL AND FIELD METHODS

INTRODUCTION

A variety of methods have been developed to identify and quantify hydrocarbons found in water. Selection of a particular method generally has reflected the specific need of the investigation, such as to measure "oil and grease" for regulatory purposes, examine oil slicks to locate the source of an unknown discharge, or to identify specific components of interest for assessing toxicity. Financial resources often have been an important factor in method selection, since many methods for measuring hydrocarbons require sophisticated equipment, highly trained personnel and a substantial time commitment.

Regulatory requirements for industrial and municipal dischargers generally have been restricted to measures of oil and grease as the only evaluation of hydrocarbon discharge. Section 307 of the Federal Water Pollution Control Act provides for toxic and pretreatment effluent standards, and a list has been published specifying pollutants subject to this Act. Routine analysis for all these pollutants is neither practical nor required by NPDES permits on individual dischargers. Furthermore, this list is not inclusive of all chemicals presenting a potential threat to health and the environment. Thus, the resultant regulations restricting oil and grease discharge only serve as a generic approach to controlling hydrocarbons--in some cases supplemented by monitoring for a few specific compounds likely to be generated by an individual discharger.

Oil and grease may not be an adequate measure of hydrocarbon pollution and potential environmental degradation. Oil and grease constitute a wide range of compounds, including vegetable oils, animal fats, soaps, waxes, esters, petroleum products, fatty acids and any other hydrocarbons extractable from water with trichlorotrifluoroethane (Standard Methods, 1985) or similar solvents. Substances such as animal fats and soaps are generally much less toxic than petroleum products. The toxicity of

petroleum products is known to vary widely and can be partially predicted from the relative concentration of various aromatic groups. Measurements of discharge quality reflecting the potential toxicity resulting from hydrocarbons and/or their sources would be useful regulatory tools. The adequacy of oil and grease as this measurement has not been established.

Numerous techniques are available to quantify specific hydrocarbon components. These techniques are generally used for a specific investigation rather than for routine monitoring. This chapter contains a review of techniques available for hydrocarbon analysis in water, with particular focus on the applicability of these techniques for routine use. Following this review is a description of the technique selected for use in this study to characterize hydrocarbons found in surface water runoff in the San Francisco Bay Area. Also described is the field program and the methods used to monitor conventional pollutants.

METHODS AVAILABLE TO EVALUATE HYDROCARBONS

A review of analytical methods for the quantitative and qualitative determination of oil and grease in water has been presented by Stenstrom (1982). This review describes in detail the development of analytical techniques to measure oil and grease, initiated largely by the wastewater treatment industry. Comprehensive descriptions of modern oil and grease analytical techniques are described in Standard Methods and many other standard references. A brief description of common techniques for the analysis of oil and grease follows as a reference to the more elaborate description of techniques available for the quantification of specific hydrocarbon fractions.

Oil and grease analysis relies on wet extraction followed by quantitative analysis of the extract. Extraction is generally done with trichlorotrifluoroethane (Freon-113), although petroleum ether, dichloromethane, or other solvents are occasionally substituted. Sodium chloride or another salt is sometimes added to improve extraction efficiency by coagulating the oil by double-layer compression. Extraction is commonly done in a

separatory funnel for materials in solution, and in a Soxhlet extraction apparatus for solids.

Quantification is accomplished either gravimetrically or using infrared spectrophotometry. Gravimetric methods, relying on drying prior to weighing, can result in the loss of volatile material and are not as sensitive to low concentrations as instrumental techniques. An infrared spectrophotometer can be used for quantification, but presents the problem of developing a reference oil to derive a calibration curve duplicating the material in the water sample. A standard method also available calls for adsorbing the polar, fatty acids on silica gel, leaving only the non-polar hydrocarbons. These non-polar hydrocarbons are then quantified gravimetrically or through the use of an infrared spectrophotometer.

Methods for the identification and/or quantification of specific hydrocarbon fractions generally rely on extraction followed by chromatographic separation and determination of individual compound.

PRELIMINARY SEPARATION

A physical process can be used initially to separate hydrocarbons associated with particulates from the total hydrocarbon load. The physical state of hydrocarbons in water is an important consideration when examining possible routes of environmental impact and environmental fate. For example, hydrocarbons associated with fairly large particles can be expected to settle out of the water column in quiescent systems. Such material would have most direct impact on organisms living in or otherwise using the sediments. Different effects would be caused by hydrocarbons found in surface slicks, such as charactistically occur when large oil spills result in the death of waterfowl.

Three inexpensive, simple methods are available for making this separation: centrifugation, filtration and sedimentation. These techniques employ common laboratory equipment suitable for routine sample analysis. The efficiency and performance of these techniques will depend on selected criteria such as filter type, centrifugation speed and settling time.

These techniques do not completely separate material associated with particles; very small particles will pass through a filter, be included with the water layer following centrifugation, or remain in suspension for extended periods. However, for general use, the distinction between hydrocarbons associated with particles (particulate phase) to those not associated with particles (aqueous phase) as determined by these techniques should be useful in assessing the environmental impact of this material.

The selection between centrifugation or filtration appears rather arbitrary. Sedimentation is not routinely used in this type of analysis, probably because of the imprecision inherent in the technique. In recent studies of hydrocarbons in water, Hunter et al. (1979), and MacKenzie and Hunter (1979), used high speed centrifugation while Hoffman et al. (1982), Eganhouse and Kaplan (1981) and Barrick (1982) used filtration through Whatman glass fiber filters (GF/C). Other recent investigations made no initial separation (Knap and Williams 1982 and Simoneit et al. 1973). Choice of technique appears to have little effect on subsequent analysis.

EXTRACTION

Most techniques for hydrocarbon analysis require separating the hydrocarbons from the water and/or associated particles. This separation is usually done through extraction with organic solvents. Liquid/liquid extraction in separatory funnels is a common method for removing hydrocarbons from water and particles. Alternatively, hydrocarbons in an aqueous phase may be adsorbed onto activated carbon or other adsorbent material followed by low temperature drying to remove water. The hydrocarbons can then be extracted from the adsorbent using procedures suitable for extracting hydrocarbons from particles.

Hydrocarbons associated with particulates (such as activated carbon or particles with adsorbed hydrocarbons in the sample) may be extracted using a Soxhlet apparatus, reflux apparatus, mixer/homogenizer, or violent stirring, grinding, or shaking. Direct comparisons are not available between the efficiency of all of the different extraction methods for specific hydrocarbon fractions, although some comparisons have been made of

individual techniques. For example, Hunter et al. (1974) found an extraction procedure using intermittent grinding with a mortar and pestle as efficient as the Soxhlet method. The use of Soxhlet extraction apparatus is currently recommended in Standard Methods (1985) when polar or heavy petroleum hydrocarbons are present, when the levels of nonvolatile grease approach the solubility limit of the solvent, or when analyzing sludges.

Jacob and Grimer (1979) recommended polycyclic aromatic hydrocarbon (PAH) extraction techniques for various types of samples. These recommendations include using boiling alkaline digestion (with methanolic potassium hydroxide) as a preliminary step in the extraction of PAH from biological material and using boiling methanol or alkaline digestion when examining soil or sediments. However, some investigators choose to use this technique for extraction from water (Hoffman et al. 1982) although most examinations of hydrocarbons in water are done using less elaborate extraction techniques.

The solvent selection is critical to the extraction efficiency and to the type of material extracted. The solvent should have a high solubility for the desired hydrocarbons, a low miscibility with water and a low boiling point to facilitate removal from the extracted material. Simple organic solvents such as pentane and hexane have been used when investigating the aliphatic hydrocarbon fraction in water (Wakeman 1977, Knap and Williams 1982, and Matsumoto 1982). These solvents will not extract polynuclear aromatic hydrocarbons, triglycerides or other polar compounds. When an organic fraction other than or in addition to aliphatics is desired to be extracted, other solvents have been used such as: dichloromethane (Hoffman et al. 1982, Blumer and Youngblood 1975, Barrick 1982, Larson et al. 1977, Herrmann 1981), chloroform (Eganhouse and Kaplan 1981, Eganhouse et al. 1982) petroleum ether (Van Vleet and Quinn 1978, Simoneit et al. 1973), trichlorotrifluoroethane (Stanken 1979), benzene (Hunter et al. 1979, MacKenzie and Hunter 1979). Choice of solvent depends largely on the desired fraction to be extracted. For example, benzene will not extract highly polar organics (such as triglycerides), unlike chloroform, petroleum ether, dichloromethane and trichlorotrifluoroethane.

Gruenfeld (1975) compared the extraction efficiency of trichlorotrifluoroethane with carbon tetrachloride to measure total oil and grease. These solvents were found to be about equally effective. However, he recommended the use of trichlorotrifluoroethane because it is less toxic to laboratory personnel than carbon tetrachloride. This example indicates that a number of factors are considered when selecting solvents, and that these factors are not restricted to extraction efficiency. Safety, cost, familiarity, purity and availability are probably significant in selecting solvents for use in many studies.

Details of extraction techniques vary considerably among studies and investigators. Choice of technique is due in part to equipment available to the researcher and familiarity with the technique. Selected procedures also reflect the specific focus of the investigation or response to interferences in the sample. Three examples are given below of procedures used in recent studies investigating hydrocarbons in natural waters.

Hunter et al. (1979) examined hydrocarbons in surface water runoff from an urban drainage area in northern Philadelphia. They first separated the aqueous hydrocarbon phase and particulate phase by centrifugation. The aqueous material was adsorbed onto activated carbon, with the aqueous phase material and particulate phase material then treated identically.

Each fraction was extracted successively with hexane, benzene, and chloroform in a Soxhlet extraction apparatus. This generated six extracts, three from the material in aqueous phase and three from the particulate phase. To separate hydrocarbons from other extractable material, the extracts were evaporated to dryness on silica gel in a rotary evaporator, with the gel subsequently charged into a chromatography column. The silica gel was then successively extracted with hexane, benzene and chloroform/-methanol to eltract, respectively, aliphatic hydrocarbons, aromatic hydrocarbons and oxy-polar compounds. Quantification was accomplished gravimetrically, with further analysis of extracts done by infrared spectrophotometry and gas chromatography.

Eganhouse and Kaplan (1981) and Eganhouse et al. (1981) examined extractable organic matter in the Los Angeles River. They first fractionated a portion of the sample by filtration through Whatman GF/A glass-fiber filters. Subsequent analysis was done identically on the filtrate and unfiltered sample.

Samples were preserved with hexane and mercuric chloride. Liquid/liquid extractions were performed successively using the hexane preservative followed by chloroform. The combined extract for each sample was concentrated by rotary evaporation and dried with anhydrous sodium sulfate. The extract was passed over activated copper to remove elemental sulfur and other extractable non-petroleum hydrocarbons. The extracts were then evaluated gravimetrically, with a portion retained for further analysis.

Simoneit et al. (1973) used a very straightforward extraction technique. Extraction followed an old standard method for oil and grease analysis, using petroleum ether rather than trichlorotrifluoroethane as currently specified in Standard Methods. Samples were filtered through a fine glass frit (approximately 5 micron pores) and extracted in separatory funnels. Each extract was washed with distilled water, concentrated in a rotary evaporator, evaporated to dryness for gravimetric analysis, and redissolved in n-hexane for subsequent gas chromatographic analysis.

Extraction of hydrocarbons is not an extremely difficult procedure, but does require specialized training and equipment. The sophistication of the technique used in different studies varies significantly, but few data are available documenting the relative advantages of different procedures.

Extraction techniques used for routine application would have to be fairly simple and inexpensive. However, some techniques are available that require little more expertise or equipment than existing procedures for oil and grease analysis, although they may take longer to perform (e.g., sequential extraction with different solvents).

EXTRACT EVALUATION

Quantification and qualitative analysis of the extracted hydrocarbons can be accomplished by a number of techniques. Investigators commonly use more than one technique in succession or parallel as a means of better characterizing each sample (Tanacredi 1977). Relatively simple techniques such as infrared spectrophotometry may be used as a screening step to determine which samples to analyze using more sophisticated (and expensive) techniques.

Gravimetric

One of the simplest methods for quantifying hydrocarbons is gravimetric. The extracts may be dried and weighed, with any identification of particular fractions accomplished through separation techniques such as filtration and extraction with various solvents. Techniques can generally follow those specified in Standard Methods, Section 503A, Partition-Gravimetric Method for Oil and Grease Analysis. The sensitivity of this technique depends in large part on sample size, although Standard Methods recommends the use of infrared spectrophotometry for concentrations less than 10 mg/l.

Infrared Spectrophotometry

Infrared spectrophotometry (IR) also is a relatively simple method for quantifying extracted hydrocarbons. The use of successive extraction prior to analysis can result in the identification of broad classes of hydrocarbons. Additionally, analysis of the infrared spectra can give information about the chemical make-up of the sample if examined by an experienced observer. Infrared spectrophotometry relies on the use of an infrared spectrophotometer. This instrument is fairly expensive, but does not require a great deal of expertise to operate. The main difficulty with this technique is that a standard oil must be used as a reference, often without knowledge of the specific constituents of the hydrocarbons in a sample. Standard Methods Section 503B, Partition-Infrared method for Oil and Grease describes the use of an infrared spectrophotometer for oil and grease analysis. The

detection limit of this technique for oil and grease is considered to be 0.5 mg/l using a 10 cm path length cell (Gruenfeld 1975).

Whipple and Hunter (1979) compared infrared adsorption to gravimetric methods for quantifying hydrocarbons. They found that IR methods generally resulted in higher readings, perhaps reflecting the loss of volatile materials during preparation for gravimetric analysis. Tischler et al. (1977) reported similar findings, with IR analysis yielding at least 20 percent more oil than gravimetric methods from a test of 19 laboratories using both methods when examining six hydrocarbon samples.

Ultraviolet and Visible Spectrophotometry

Hydrocarbons containing conjugated bonds have characteristic absorption spectra in ultraviolet (UV) and visible regions. Ultraviolet and visible spectrophotometric techniques are commonly used with thin layer chromatography (TLC) and high pressure liquid chromatography (HPLC) (both methods described below) for detection and quantification.

The use of UV spectrometry is typically reported from investigations using a variety of techniques to allow a comprehensive characterization of hydrocarbons in a sample. For example, Giger and Blumer (1974) used column chromatography, visible spectrometry, UV spectrometry and mass spectrometry to isolate and characterize PAH sediments. DiSalvo et al. (1976), examining hydrocarbons in marine algae, used UV to detect hydrocarbons from TLC plates, following separation using column chromatography and prior to analysis with mass spectrometry.

Column Chromatography

Column chromatography has been used extensively to separate hydrocarbons in approximate order of molecular weight, frequently using alumina or silica as the adsorbent substrate. Hydrocarbons may be sequentially removed from the column through the use of successive solvents, such as hexane to extract aliphatic hydrocarbons followed by benzene to extract aromatic hydrocarbons.

Furthermore, hydrocarbons will extract in approximate order of molecular weight, allowing for additional identification.

While column chromatography does not allow for as complete sample resolution as other chromatographic methods (Kunte 1979), it is fairly easy and inexpensive to perform. Column chromatography can be very useful to clean up a sample prior to analysis (Blumer and Youngblood 1975). Quantification and some identification of extracted compounds can be done gravimetrically or through instrumentation techniques such as fluorometry, IR spectrophotometry or UV spectrophotometry.

Gas Chromatography

Gas chromatography (GC) has frequently been used to separate, identify and quantify hydrocarbons. Analysis by GC is relatively complicated, requiring fairly expensive equipment and trained personnel. It is extremely sensitive, particularly when using a flame ionization detector or electron capture detector. Harrison (1975) reports a detection limit of 5-20 ng per injection for all PAH compounds smaller than coronene (C-24). However, using these detectors does not normally allow identification of the material responsible for a given peak. An unresolved complex mixture is characteristic for GC profiles of petroleum hydrocarbons, with a broad envelope of unresolved species extending from n-C13 to n-C36 (Erhardt and Blumer 1972). Gas chromatography - mass spectrometry (GC/MS) allows greater identification of the hydrocarbons (Lao et al. 1973), but is only about one tenth as sensitive as a flame ionization detector (Harrison et al. 1975).

Furthermore, the amount of data may be overwhelming as a means of characterizing a sample, and would probably be too expensive for routine analysis. Gas chromatography and particularly GC/MS are probably best used for special studies identifying specific hydrocarbon components in a sample.

Several recent studies have used GC techniques to quantify hydrocarbons in natural water, wastewaters, animal tissue, sediments and other particulate matter. Examples include examination of:

- o lake and river sediments, river particulates, street dust and airborne particulates by Giger and Schaffner (1978);
- o urban stormwater runoff by Hoffman et al. (1982), Hunter et al. (1979), MacKenzie and Hunter (1979), and Matsumoto (1982);
- o sediments and sludge by Matsumoto (1983);
- o river and creek water, urban stormwater runoff and rainfall by Wakeman (1977);
- o sediments by Van Vleet and Quinn (1978);
- o municipal waste water by Barrick (1982).

Gas chromatography may be used as a final detection and identification procedure, following simpler procedures such as TLC or column chromatography.

Nuclear Magnetic Resonance Spectrometry

Nuclear magnetic resonance spectrometry (NMR) has been shown to be valuable in characterizing the chemical structure of hydrocarbons, supplementing information supplied by GC/MS and other techniques. Guard and Coleman (1980) used NMR to investigate the biodegradation of complex hydrocarbon mixtures, while Lee et al. (1976a, b) used this technique investigating airborne particulates and tobacco and marijuana smoke condensates. While NMR extends the analytical ability to precisely define the make-up of a compound, its applicability appears to be most suited for use in toxicity and other special studies for which the determination of the precise chemical formulation of a compound is important.

Thin Layer Chromatography

Thin Layer Chromatography (TLC) offers an alternative means for sensitive separation and analysis of hydrocarbons. An advantage of this method is

the lack of interferences, allowing extracts to be examined directly. Potential interferences either remain at the origin, such as triglycerides, or do not char, such as chlorinated hydrocarbons (Guard et al. 1980). Sawacki et al. (1964) examined the merits of alumina and acetylated cellulose as stationary phases for separated polynuclear aromatic hydrocarbons and concluded that the best results were obtained using a mixture of the two materials. However, several recent studies report the use of silica gel (Eganhouse and Kaplan 1981, 1982, Eganhouse et al 1981, Larson et al. 1977, Guard et al. 1980, Van Vleet and Quinn 1978, Knap and Williams 1982).

Guard et al. (1980) separated hydrocarbons using TLC from marine sediments into alkanes, alkenes and arenes. Quantification was done by direct photodensitometry of charred spots using a mixed aliphatic and aromatic standard. They found that this method resulted in relative errors ranging from 18 percent to 45 percent compared to gravimetric determinations following Standard Methods. Eganhouse et al. (1981) used TLC to identify five hydrocarbons fractions: (1) total hydrocarbons, (2) fatty acids, (3) ketones, (4) polar compounds and (5) non-extractable polars. Quantification was done using GC/MS. Knap and Williams (1982) used similar TLC techniques, but identified a different set of hydrocarbon fractions: (1) alkanes, cycloalkanes, (2) olefins, 1 and 2 ring aromatics, (3) 3 ring aromatics, (4) 4 ring aromatics and (5) 5 ring and greater aromatics.

High Pressure Liquid Chromatography

High pressure liquid chromatography (HPLC) offers more sensitivity than thin layer chromatography, but requires additional investment in equipment and expertise. High pressure liquid chromatography is particularly useful for the separation of compounds which are not easily amenable to gas chromatography because of high boiling points or instability at the temperatures necessary for GC (Kunte 1979). A variety of different columns are regularly used for HPLC, with fluorescent spectrophotometry or UV spectrophotometry usually used for detection. Grzybowski et al. (1983) recently specified a technique for the isolation, identification and determination of PAH in sewage using HPLC. Other recent applications of

HPLC to examine hydrocarbons include the work of Herrmann (1981) on urban runoff and the work of Eadie et al. (1982) on sediments, pore water and an amphipod.

Eadie et al. (1982) compared replicate analysis of polycyclic aromatic hydrocarbons by GC and HPLC analysis. Coefficients of variation for individual compounds ranged from 5 percent to 25 percent, with a systematic difference observed. Values for anthracene, phenanthrene and fluoranthene resulting from each technique corresponded closely, while significantly higher levels were measured on the HPLC than on the GC for pyrene, chrysene and benzo(a)pyrene. The U.S. EPA has published a test method (Strup 1982) for identifying and quantifying certain PAH. Sensitivity using HPLC ranges from 0.013 ug/l for benzo(a)anthracene to 2.3 ug/l for acenaphthylene.

Fluorescent Spectrophotometry

Fluorescent spectrophotometry (FS) has been used to measure hydrocarbons both through examination of extracts and through direct sample examination. Fluorescence can be used for spill source identification as well as quantification (Frank 1978). Applications include use for detection and identification as part of a comprehensive analytical technique as well as providing an independent means of sample analysis.

Bajnocy and Kasa (1980) report the use of fluorescence spectroscopy as a very simple measure of petroleum hydrocarbon contamination. They extracted hydrocarbons with n-heptane and measured the extract directly with a spectrofluorometer, using excitation wavelength of 280 nm and emission wavelength of 340 nm. This technique was able to detect hydrocarbons at 0.01 mg/l using an initial water sample of only one liter. However, the accuracy of this determination depends on the suitability of the reference oil. At the low concentrations tested for a sample with unknown hydrocarbons constituents, the error may be as large as 100 percent.

Maher (1983) extracted aromatic hydrocarbons from water using methylene dichloride prior to fluorescence spectroscopy. Solutions were excited at 300 nm and the emission scanned from 310-500 nm. Several crude and refined

oils were scanned, with a distinction noted suitable for distinguishing between major groups of aromatic compounds in the sample. Oils with predominantly 2- and 3-ringed aromatic structures had fluorescence emission maxima at approximately 330 nm, while compounds with greater numbers of ring structures had maximum emission at approximately 380 nm. Based on these results, Maher selected two pure compounds as suitable reference standards for different applications, m-terphenyl and chrysene, which fluoresce at 330 nm and 380 nm, respectively.

Maher (1983) reported sensitivity of this technique to 50 ng/l. Spiking samples with 1 ug of known oils resulted in recoveries of greater than 95 percent with standard deviation no more than 3 percent. Materials common to natural waters (humic acid, chlorophyll pigments, detergents) added to standards showed negligible interference to test results.

These recent applications indicate a promising potential for use of fluorescence spectroscopy for a rapid evaluation of aromatic hydrocarbons in water. Scanning of solvent extracts, perhaps done in conjunction with routine oil and grease testing, may reveal significant information about the quantity and characteristics of the aromatic fractions. Since toxicity generally increases with greater number of ring structures, separation of compounds using two emission wavelengths may provide important environmental information. Fluorescence spectrometry may have the potential to provide a practical alternative to gravimetric and IR methods, particularly in situations investigating contamination from suspected sources with known hydrocarbon constituents.

Limited investigation has also been made of the potential to use FS to directly measure hydrocarbons in-situ, eliminating the need for extraction. Frank (1973) directly measured hydrocarbons in water using single wavelength excitation fluorometric techniques, while Frank and Gruenfeld (1978) reported some additional success using synchronous excitation fluorescence spectroscopy. However, these in-situ techniques have not been adequately demonstrated to determine their potential for routine use.

TECHNIQUE SUITABILITY FOR ROUTINE ANALYSIS

Numerous techniques are available for the analysis of hydrocarbons. These techniques provide a spectrum of options, ranging from the fairly simple and inexpensive to relatively sophisticated and demanding. In selecting a method for use, the information to be generated needs to be examined with regard to both potential usefulness and cost. The two major considerations for assessing the appropriateness of techniques for monitoring surface runoff and municipal wastewater effluent into San Francisco Bay are (1) the information generated about the toxicity of the discharge and the sources of the hydrocarbons and (2) the practicality (cost) of obtaining that data. The capabilities and requirements of the procedures described above for examining hydrocarbons are summarized in Table II-1.

While the toxicity of hydrocarbons varies substantially between different compounds, some general trends are apparent which allow for examining hydrocarbon groups rather than individual species. Preferred techniques suitable for routine analysis should separate and identify groups of compounds indicative of the sample toxicity and/or hydrocarbon origin. While "lumping" compounds together to form general groups indicative of toxicity may not be precise, it can allow for development of inexpensive methodology applicable for routine analysis generating considerably more information than oil and grease measurements.

The toxicity of a given oil can be partially predicted from the relative concentration and nature of various aromatic and alkyl groups. Low molecular weight straight chain hydrocarbons tend to be easily degraded by bacteria and are relatively less toxic than aromatics (Farrington and Quinn 1973). Toxicity generally increases with increases in the number of rings in a compound up to 4 and 5 ring aromatic structures. Larger molecules generally have toxic concentrations above their solubility limits (Rice et al. 1977).

Relative concentrations of various organic fractions may also provide useful information regarding hydrocarbon sources. For example, heavy n-alkanes are usually associated with biogenic sources, with C-29 and C-31 usually in greatest abundance (Eglinton and Hamilton 1967; Castillo et al.;

Table II-1. Summary of Hydrocarbon Analysis Techniques

Technique	Equipment Requirements and Availability	Level of Laboratory Personnel	Time for Analysis (Following Preliminary Extraction)	Cost of Representative Equipment	Analytical Capabilities and Limitations
Gravimetric	Balances. Available in almost all laboratories.	Little training required. Technician level.	Minutes/sample.	\$3,000-\$8,000	Quantification of extracted materials. Some loss of volatile materials.
Infrared spectrophotometry	Infrared spectrophotometer. Available in many laboratories.	Some training required for operation and standard preparation. Entry or journeyman level chemist.	Minutes/sample following instrument set-up calibration and standard preparation.	\$5,000-\$25,000	Detection and quantification of extracted material with potential for some qualitative assessment by trained personnel.
UV and visible spectrophotometry	Infrared spectrophotometer. Available in many laboratories.	Some training required for operation and standard preparation. Entry or journeyman level chemist.	Minutes/sample following instrument set-up, calibration and standard preparation.	\$5,000-\$25,000	Detection and quantification of extracted material with potential for some qualitative assessment by trained personnel.
Column chromatography	Chromatography columns and packings. Not common but easily obtained.	Not routine procedures. Entry or journeyman level chemist.	Several hours/sample, although not requiring constant attention.	Chromatography tubes #11-34 (10 mm ID) Silice gel column sorbents #32-72 (500 grams).	Fractionate sample. Detection and quantification subsequently done by other techniques. Useful for preliminary sample "cleanup."
Gas chromatography	Gas chromatograph with suitable detector. Available in many laboratories. Mass spectrometer detector not commonly available, but easily obtainable	Considerable training required for comprehensive analysis. Journeyman or senior level chemist.	Highly variable depending on specific technique. At best, limited to a few samples/day.	\$5,000-\$20,000 for GC, other significant set-up costs	Fractionate sample with potential for sensitive identification and quantification. Usually needs preliminary sample cleanup.

Table III-1. Summary of Hydrocarbon Analysis Techniques
(Continued)

Technique	Equipment Requirements and Availability	Level of Laboratory Personnel	Time for Analysis (Following Preliminary Extraction)	Cost of Representative Equipment	Analytical Capabilities and Limitations
Nuclear Magnetic Resonance Spectroscopy	Nuclear magnetic resonance spectrophotometer. Not common laboratory equipment. Obtainable from a few manufacturers.	Considerable training required. Journeyman or senior level chemist.	Variable, but limited to a few samples/day. Complex preliminary analysis required.	>\$20,000	Useful in characterizing chemical structures.
Thin layer chromatography	Thin layer chromatography plates, developer, and method for detection. Available in many laboratories and easily obtained.	Some training required. Entry or journeyman level chemist.	Variable, but relatively rapid technique.	Glass pre-coated silica-gel plates, \$44-550 (package of 25).	Useful in separating fractions. Not comparable to other techniques.
High pressure liquid chromatography	High pressure liquid chromatograph. Not common laboratory equipment. Obtainable from a few manufacturers.	Considerable training required. Journeyman or senior level chemist.	Highly variable depending on specific technique. At best, limited to a few samples/day.	>\$10,000 significant set-up costs.	Complements GC techniques for identifying compounds. Quantification subsequently done by other means.
Fluorescent spectrophotometry	Fluorescence spectrophotometer. Not common laboratory equipment. Available from a few manufacturers.	Not routine procedure. Journeyman level chemist.	Rapid following equipment set-up and calibration. Minutes/sample.	\$3,000 and up.	Potential for use for qualitative analysis not adequately explored. Useful as means of detection.

Bottari et al.; and Casadevall et al. 1985). Conversely, diesel fuel characteristically shows an abundance of lighter alkanes ranging from C-10 through C-25.

Using these generalizations as a basis for devising suitable analytical techniques, it appears that valuable information would be the proportion of aliphatic and aromatic hydrocarbons, and the size of the compounds. The techniques selected for use in this study offer a means of determining these proportions, as well as total hydrocarbon load, using conventional oil and grease extraction and detection equipment supplemented by an automatic shaker/stirrer system and column chromatography.

The selected technique involves the separation of particulate and aqueous phase hydrocarbons by filtration, extraction and detection for oil and grease, fractionation through successive extraction using column chromatography and detection of aliphatic, aromatic and oxy-polar groups using gravimetric techniques. Fractions will be evaluated further using GC analysis and comparisons to other conventional measures such as Total Organic Carbon, Total Oil and Grease and Solids.

Liquid chromatography was chosen as the initial fractionation technique instead of thin layer chromatography (TLC) because of its simplicity. Columns are very easy to prepare and no pre-treatment of extractable organics is necessary to render the four fractions. Although TLC fractionation requires less than one half the amount of solvent used in the liquid chromatography procedure, TLC requires greater expertise, and if only one solvent is used to develop the TLC plates, the extractable organics must be esterified if polar compounds are to be eluted (Eganhouse et al. 1981). An alternate thin layer chromatography procedure using multiple solvent systems to circumvent pre-treatment may yield significantly improved separation, but render the procedure cumbersome for routine analysis. Additionally, liquid chromatography is much more amenable to handling large quantities of extractable organics (10-40 mg) than TLC plates. Thin layer chromatography would be more appropriate if the extractable organic quantities were less than 0.25 mg; however, such small quantities would be very difficult to analyze gravimetrically.

An alternative approach, not selected for use in this study, also offers considerable potential for distinguishing important hydrocarbon groups. This approach uses fluorescent spectrometry following solvent extraction. This technique requires the use of a fluorescent spectrophotometer, a less common detector than either an infrared spectrometer or a balance suitable for oil and grease analysis. This technique can be relatively inaccurate, particularly when the composition of the hydrocarbons is unknown. However, through scanning at different wavelengths, more information may be quickly generated regarding aromatic chain length than can be generated using IR and gravimetric techniques. The results of this current study may indicate the need for further investigation of fluorescence techniques for sample characterization.

SELECTED METHODOLOGY

The methodology described below was developed as a cost-effective measure of hydrocarbons in surface water runoff and municipal effluent more adequately reflecting toxicity and origin than oil and grease techniques. The selected procedure is shown schematically on Figure II-1.

The collected samples were first filtered through a 0.45 micron Whatman glass fiber filter. Particulates were extracted with methylene chloride using a Soxhlet extractor for 12 hours to remove the adsorbed extractable organics from the particulate surfaces. Organic compounds in the soluble fraction were collected by using liquid/liquid extraction. The particulate and soluble fractions were treated identically after extraction.

Liquid/liquid extractions of filtered 4-liter water samples were performed using three successive 250 ml portions of methylene chloride. Twenty grams of sodium chloride were added to the solution to break emulsions. This reduces the needed amount of sodium sulfate for final drying and minimizes the loss of extracted organics in the filtration step used to remove the hydrated sodium sulfate. Each of the three

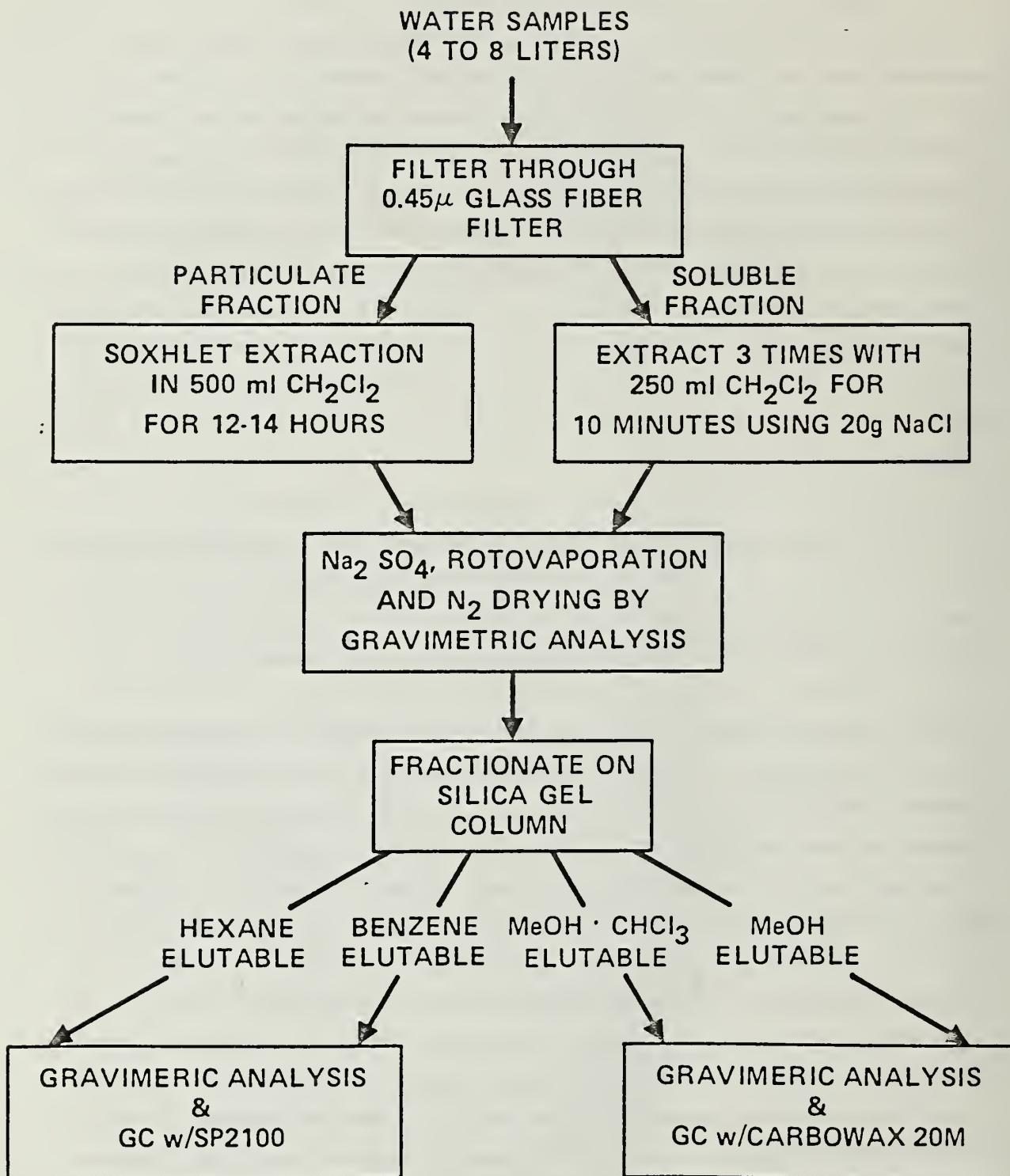


Figure II-1. Selected Analytical Procedure

methylene chloride portions was shaken and stirred with the water sample for 10 minutes using the automatic shaker/stirrer system shown in Figure II-2.

Methylene chloride was the solvent of choice because of its low boiling point, high density, high dipole moment for extraction of polar organic compounds, and low cost. Comparisons show it to have nearly identical efficiency to trichlorotrifluorethane, the solvent recommended for oil and grease analysis by Standard Methods; however, methylene chloride is considerably less expensive.

The extracts for both particulate and soluble fractions of each sample were concentrated to a small volume (10-15 ml) by rotary evaporation at 32°C, and the concentrated solutions were dried further with anhydrous sodium sulfate. The resultant water-free methylene chloride extracts were transferred to tarred 25 ml flasks, dried by rotary evaporation with final drying under a gentle nitrogen gas stream for approximately 10 minutes at 37°C. Gravimetric analysis was performed on a Mettler electrobalance for extractable organics.

The automated shaker/stirrer system shown in Figure II-2, improves extraction precision by allowing the use of large quantities of sample. Normally it is difficult to handle samples as large as 4 liters, but samples as large as 8 liters can easily be managed with this apparatus. The large sample volume increases the quantity of extracted organics which improves gravimetric precision and accuracy. Extending extraction times (>10 minutes) does not result in increased extraction efficiency.

Gravimetric precision is higher in this procedure than that recommended by Standard Methods due to the increased sample size (4 liters versus 1 liter) and also because of the smaller weighing flask. Standard Methods recommends a 125 ml weighing flask which is considerably larger than the 25 ml weighing flask used in this study. Increased accuracy was needed in order to avoid using the infrared spectrophotometric method, which is recommended by Standard Methods for samples containing oil and grease concentrations in the range expected for this study. It was desirable to avoid the infrared method, even though it is more sensitive, because of

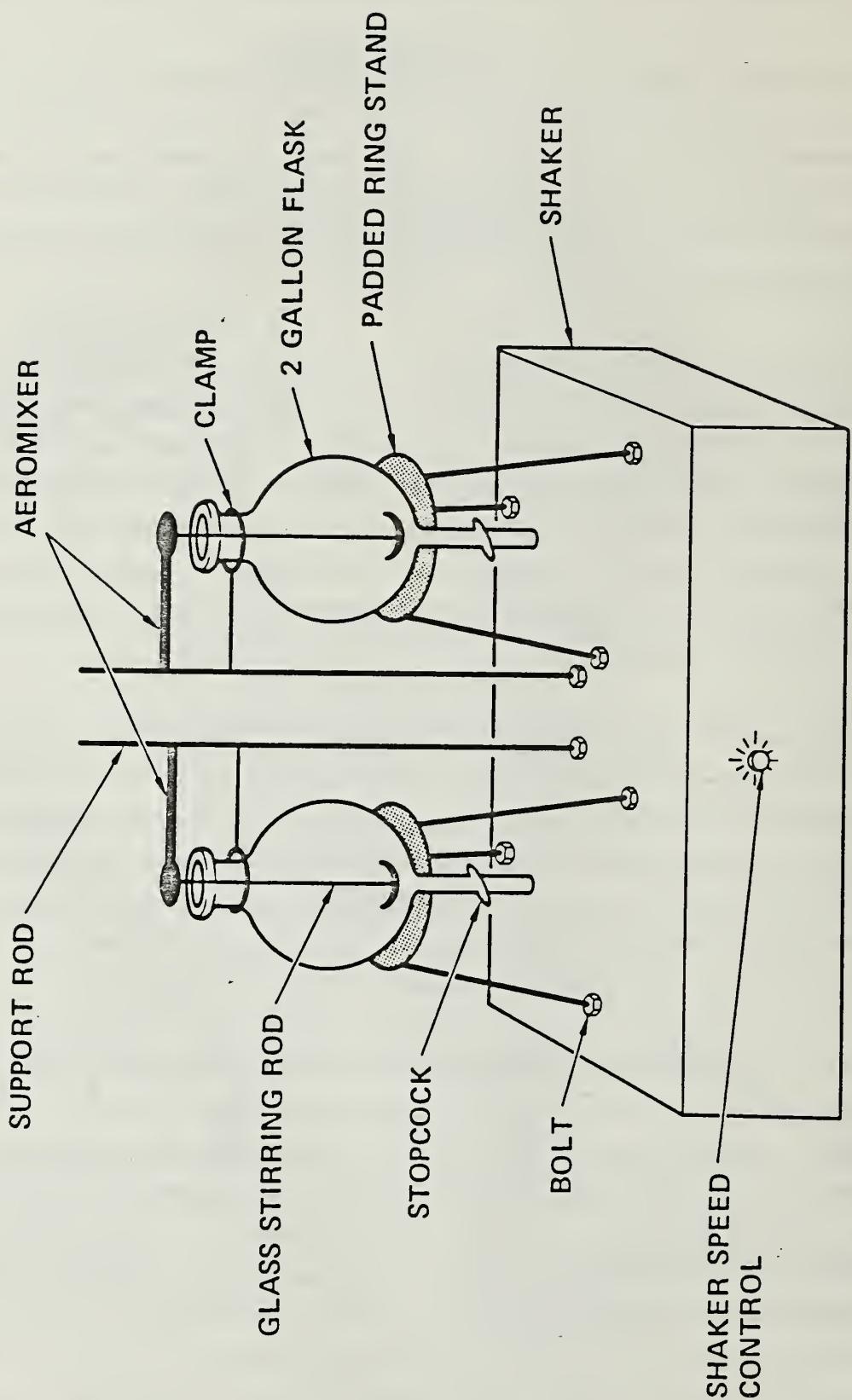


Figure II-2. Extraction Apparatus

sample losses associated during filling and emptying the IR cells, which hamper the fractionation analysis. Furthermore, calibration of an IR instrument for oil and grease analysis is specific to the types of compounds used for calibration. It is not possible to select a "standard" oil and grease compound. An important aspect of this study relates to the expected differences in oil and grease compounds from different land uses. The IR method might distort or mask these differences due to its calibration procedure. The IR method also underestimates the quantity of aromatic compounds present, which is a significant aspect of this investigation. IR spectra can be used for qualitative analysis and some samples were analyzed using scanning spectrophotometry.

The extracted organics were separated into a non-aromatic hydrocarbon, an aromatic hydrocarbon, a polar fraction, and a very polar fraction by liquid chromatography. Deactivated silica gel (40-140 mesh) was used as the adsorbent in a 1.9 cm diameter column. The silica gel was cleaned by extracting with methylene chloride for 12 hours, since significant quantities of methylene chloride extractable contaminants were present. Non-aromatic hydrocarbons were extracted with 1.5 to 2 column lengths of hexane; 1.5 to 2 column lengths of benzene were used to extract aromatic hydrocarbons, 1.5 to 2 column lengths of 1:1 chloroform-methanol were used to extract the polar compounds, and three column lengths of methanol yielded the very polar fraction. Non-extracted hydrocarbons retained on the silica gel were quantified by the difference in total extract weight obtained in the previous step and extract weights of the extracted fractions. A 14 cm silica gel column was sufficient to separate 30 mg of extractable organics.

The four fractions were examined by high resolution fuse silica columns using a Varian Vista 6000 gas chromatograph equipped with a splitless injector and hydrogen flame ionization detector. The first two fractions were analyzed using a fuse silica SP 2100 column (22 m, 0.25 mm internal diameter). For the first fraction, the injector temperature was 275°C, with oven temperature programmed from 50°C to 280°C at a rate of 4°C per minute, following an initial hold of 4 minutes and isothermal conditions at 280°C held for 20 to 30 minutes. Detector temperature was 300°C, and carrier gas flow (helium) was 21 psi. The second fraction was programmed from 100°C to

280°C at 4°C per minute, with no initial hold and isothermal conditions held for 20 to 30 minutes at 280°C. Detector temperature was 280°C with gas flow of 21 psi. A 30 meter, 0.25 mm internal diameter carbowax 20M column was used to analyze the two polar fractions. Injector port temperature was 215°C, oven temperature was programmed from 70°C to 205°C following a 4 minute initial hold with about a 50 minute final hold at 205°C. Detector temperature was 230°C, with carrier gas flow of 22 psi.

TECHNIQUE PERFORMANCE

The selected analytical procedure was tested for extraction and separation efficiency using an aqueous solution of octadecane, anthracene, and 1,2 hydroxystearic acid. In addition, extraction of a highly polar compound, phenol, was tested. Table II-2 shows the results of the extraction efficiency.

Table II-2. Recoveries of Various Organics Using the Selected Procedure

<u>Compound</u>	<u>mg in Solution</u>	<u>Percent Recovery</u>
Octadecane	21	99
Anthracene	31	99
1.2 Hydroxystearic acid	36	94
Phenol	40	89

GC analysis showed minor carry over of the anthracene into the octadecane fraction, but separation was over 90 percent. No carry over with 1,2 hydroxystearic acid was observed. The lower recoveries for phenol and 1,2 hydroxystearic acid are attributed to the extraction step, since no loss was detected in the fractionation.

CONVENTIONAL POLLUTANT MEASUREMENTS

Oil and Grease, pH, Specific Conductivity, Total Organic Carbon, Turbidity, Total Non-filterable Residue (TNR) and Total Filterable Residue (TFR) were measured to evaluate their potential to serve as indicators of hydrocarbon pollution. Test procedures generally followed Standard Methods, although dichloromethane was used as the extracting solvent rather than freon in analyzing for oil and grease. The specific tests used for analysis are shown on Table II-3.

Table II-3. Methods For Measuring Conventional Pollutants (from Standard Methods.)

<u>Test Name</u>	<u>Number</u>	<u>Comments</u>
Grease & Oil/Partition-Gravimetric Method	502 A	dichloromethane used in place of freon
pH		
Specific Conductivity		
Organic Carbon (Total)	505	Ionics 1270 TOC Analyzer
Turbidity	214 A	
Total Dissolved Solids Dried at 103-105 C	208 C	Standard Methods Fourteenth Edition
Total Suspended Solids Dried at 103-105 C	209 C	

FIELD PROGRAM

The sampling program was designed to collect samples representative of a diversity of conditions in the San Francisco Bay Area. Land uses for each of the sampled watersheds were determined as described in Chapter III. Sample station locations are shown on Figure II-3.

In a previous phase of research, oil and grease concentrations were examined at several stations within a watershed, with samples taken at regular intervals during the active part of a storm and discharge measured (Stenstrom et al. 1982, 1984). Oil and grease concentration was not significantly related to storm parameters, including time during the storm and time between storms, except for a strong correlation between total oil and grease and total rainfall. Similarly, Eganhouse and Kaplan (1981) did not find strong correlations between flow or suspended solids and extracted organic fractions, although Hoffman et al. (1982) reported a "first flush" of hydrocarbons at the beginning of a storm. Based on this experience, a field program was developed to sample at a maximum number of sites representing different combinations of land uses. While flow characteristics could not be examined, this program allows substantial evaluation of the relationships between measured parameters representing a large variety of conditions. Of particular interest is the uniformity (or lack thereof) of particular hydrocarbon fractions extracted by the oil and grease test as a function of land use.

Grab samples were taken at widely scattered stations throughout the San Francisco Bay Area. One sample was taken during each sampling period, and the nature of the flow at the time of sampling was described as: (1) during or immediately following an active rainfall period with considerable flow, (2) following peak flow but with considerable storm flow still in the channel, (3) at the tail end of the storm hydrograph or following a storm with base flow conditions, or (4) dry season. Sampling dates are shown on Table II-4. Insufficient water was available in three stations to allow dry season sampling. Two additional samples were taken in April, 1985 to confirm the location of a suspected source of diesel fuel in the Temescal Creek watershed.

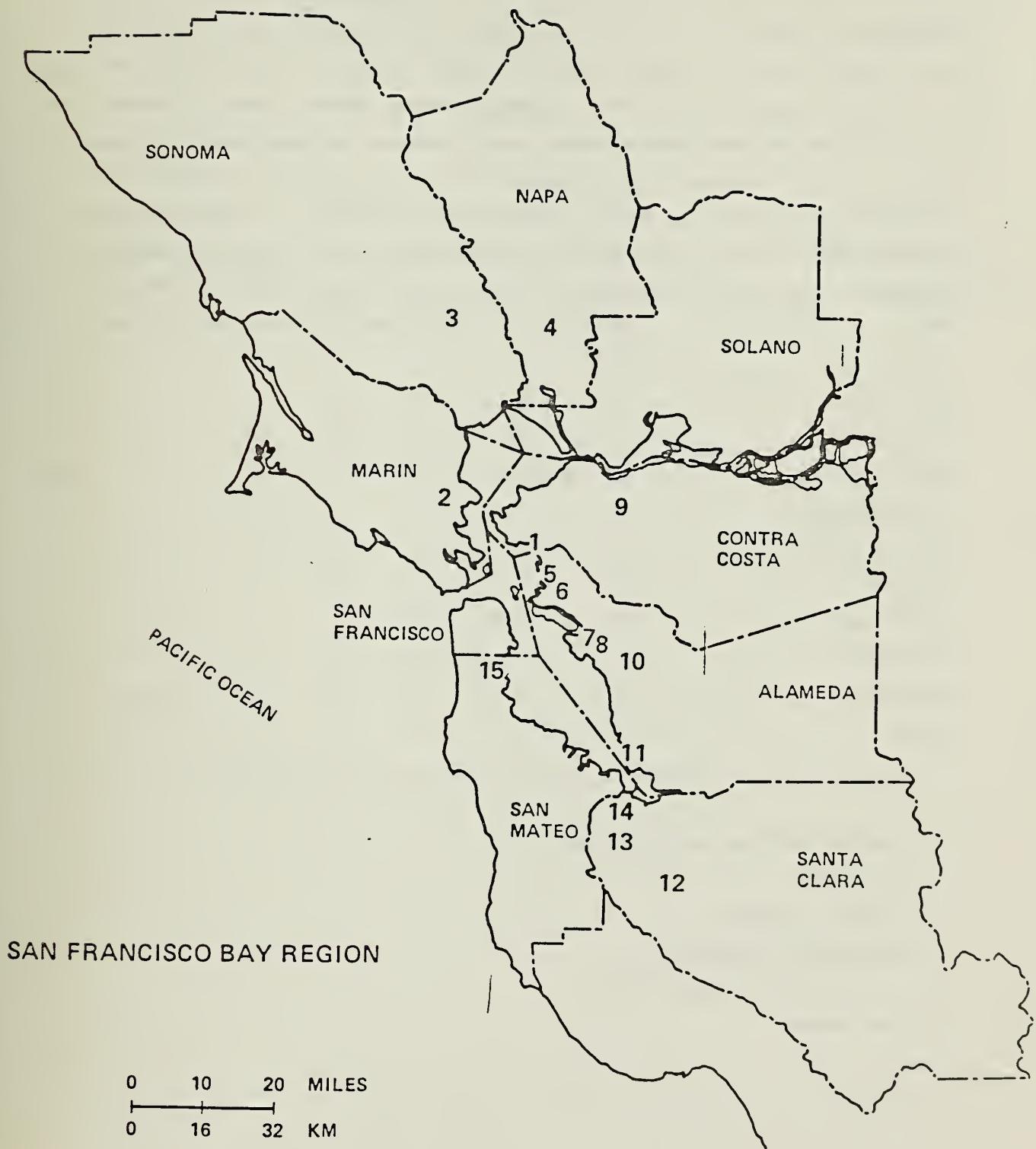


Figure II-3. Sample Station Locations

Table II-4. Sampling Schedule

Station	Storm Type						
	Date						
	April 1984	July 1984	Oct 1984	Nov 1984	Dec 1984	Jan 1985	March 1985
Richmond	3	4	1	1	-	1	-
Sleepy Hollow	3	4	1	1	a	1&3	-
Sonoma	3	4	1	1	-	1	-
Napa	3	4	1	1	-	1	-
Temescal	1	4	3	1	-	2	1
Glen Echo	1	-	3	1	-	1	-
Arroyo Viejo	1	4	3	2	-	-	1
Elmhurst	1	4	3	2	a	-	1&2
Pine-Galindo	2	-	1	1	-	-	1
Castro Valley	1	4	3	2	-	1	-
Crandall	2	-	3	2	-	1	-
Guadalupe	2	4	3	2	-	1	-
Calabazas	2	4	3	3	-	1	-
Matadero	2	4	3	3	-	1&3	-
Colma	2	4	3	3	-	2	1

a = hourly monitor during storm

- = no sample

1 = active rainfall

2 = following peak rain

3 = low flow following storm

4 = dry season

Samples were collected either directly in one gallon (3.78 l) solvent cleaned glass bottles, or in a stainless steel bucket and quickly transferred to a glass bottle. The bucket was cleaned prior to sampling by several rinses in the runoff. Samples were taken at turbulent locations, where possible, to ensure a uniform sample. When turbulent zones did not exist, flow was generally sufficiently low to allow sampling of the entire water column with the bucket. These samples were acidified on-site with concentrated hydrochloric acid (solubilizing an unknown fraction of the particulates). Additional samples were taken in 1-liter (0.26 gal) polyethylene bottles for analysis of solids, total organ carbon (TOC) and turbidity. All samples were cooled in ice chests, and kept refrigerated in the laboratory until analyzed.



CHAPTER III

MODEL DEVELOPMENT

INTRODUCTION

The sampling results are used with the ABMAC planning model to assess the extent of hydrocarbon loading throughout the region and predict anticipated changes due to development and implementation of remedial measures. This model was used in an earlier stage of this work, examining oil and grease in runoff from a watershed in Richmond (Contra Costa County), California (Stenstrom et al. 1982, 1984). In this earlier stage, the model was calibrated based upon results obtained from sampling for oil and grease during one rainy season from seven stations representing different combinations of land use within the single watershed. Estimates of loading to the Bay were made only for this single watershed. In the current study, verification is made of the coefficients previously found to describe oil and grease, using data from the fifteen sampling stations, with re-calibration conducted as necessary. The model is then applied to predict loading from all local runoff sources into San Francisco Bay.

The ABMAC model was selected for use in this study as it provides a relatively simple method for generating reasonable estimates of pollutant loading into the Bay. While other models are commonly used, particularly the U.S. EPA Storm Water Management Model (SWMM) (Huber et al. 1975) and the Army Corps of Engineers (1975) Storage, Treatment, Overflow and Runoff Model (STORM), their application to this study was limited by the nature of input data and the desired output. The ABMAC Model was preferred for this study as it utilizes the greatest degree of accuracy possible from the experimental measurements.

MODEL DESCRIPTION

ABMAC is the Association of Bay Area Governments (ABAG) Macroscopic Planning Model (MAC). A brief description of the model is presented here.

A more detailed account is available in the model documentation and user's guide (Litwin et al. 1980).

ABMAC is a continuous simulation model based on simple concepts of hydrology and water quality. For this reason its data input requirements are minimal. It requires rainfall data, areas devoted to specific land uses, and pollutant concentrations and runoff coefficients. Any watershed can be divided into as many as 99 subareas, each of which can be characterized by up to six land uses. Up to six water pollutants can be studied. Storage, treatment and overflow can all be simulated. Calculations are made using a daily time step.

Runoff is calculated using the rational method:

$$R = kAr \quad (\text{III-1})$$

where R = runoff

k = runoff coefficient

A = area

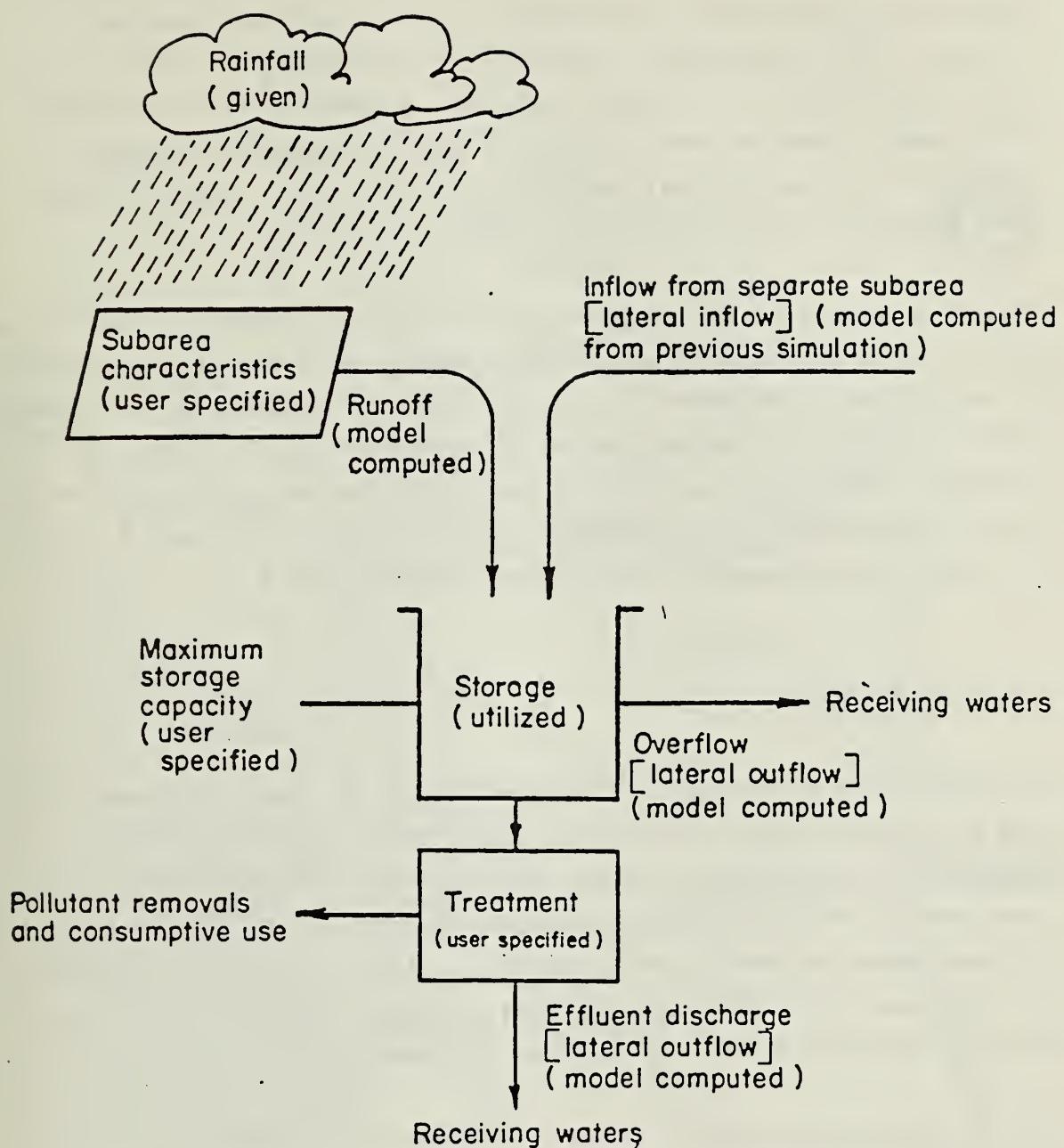
r = rainfall.

Water quality is represented by a pollutant concentration C :

$$M_p = CR = CkAr \quad (\text{III-2})$$

where M_p is the pollutant load, the total mass of pollutant produced. Both the runoff coefficient k and the pollutant concentration C are considered to be constants in this model. A diagram of the model operation is provided in Figure III-1.

There are several places where simplifications in the model can lead to inaccuracy. The runoff coefficient is not really constant. Dry land will absorb more water than saturated land. The runoff coefficient can thus vary during a storm, and from season to season. For this reason, ABMAC is really intended as a yearly model. If used to compare different years of



Note : Simulation repeated for each subarea (computational unit)

SCHEMATIC REPRESENTATION OF ABMAC CONCEPT

Figure III-1. Schematic Diagram of the ABMAC Model
(Metcalf and Eddy, 1980)

data, the errors introduced by using a typical runoff coefficient will tend to average out. The constant k can lead to errors in considering the flow from any one particular storm, however. This can make calibration difficult. The assumption of a constant pollutant concentration discounts first flush effects or any other variation of concentration with time or flow. Again, since an average value is used, the total result over the course of a year may be quite reliable. No time lag, percolation rate, or other hydrologic complication is included.

It must be noted that the simplifications will not necessarily lead to less exact results than would a more complex model. In assuming a constant value of k one avoids errors in analysis of the variations of k. A complex model can only yield better results if one has the data to properly calibrate and run the model. The ABMAC model provides a flexible, easily applied tool for the study of water quality in watersheds where hydrology and water quality have not been extensively documented.

MODEL APPLICATION

The ABMAC model was originally designed for use by the Association of Bay Area Governments (ABAG) as a tool in formulating the Surface Runoff Management Element of the regional Environmental Management Plan prepared under Section 208 of the Federal Water Pollution Control Act. The local drainage comprises about 5,600 square miles in nine counties surrounding San Francisco Bay (Figure III-2). This drainage has been divided into discrete units for modelling purposes with ABMAC.

For the orginal application of ABMAC, 110 modelling units were specified in the Bay Area drainage. For modelling purposes, each of these units is characterized by rainfall and land use, with coefficients determined representative of pollutant concentrations and the runoff/rainfall ratio for each land use.

Nine precipitation gauging stations reporting to the National Oceanic and Atmospheric Administration (NOAA) are used to provide data for each

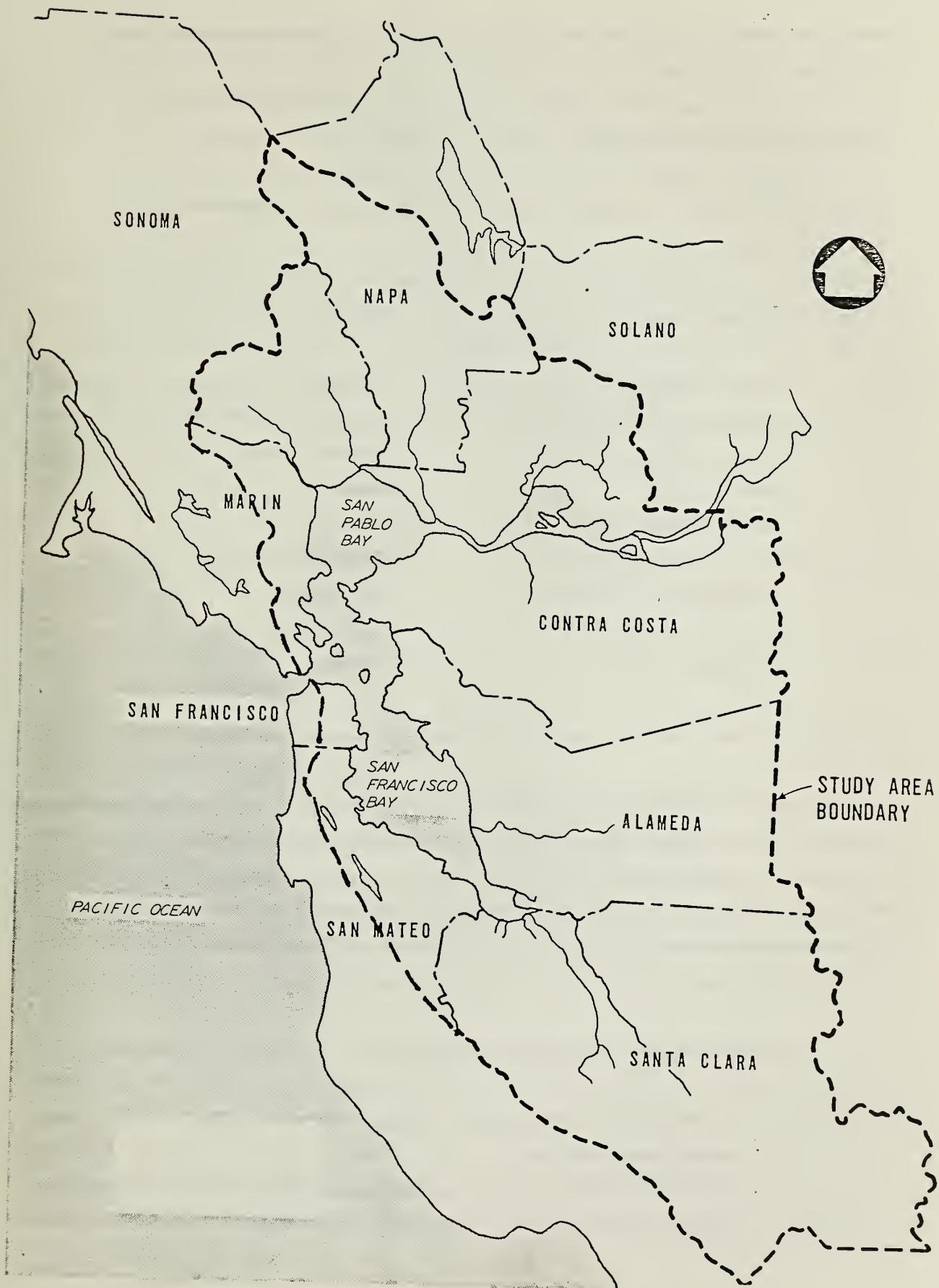


Figure III-2. Local Drainage in San Francisco Bay

modelling unit in the Bay Area (Table III-1). Coefficients are used to account (on average) for differences between precipitation at the stations and the modelling unit. Information from NOAA was obtained for use in this current study for these stations.

Table III-1. Precipitation Stations Used in ABMAC Model

<u>Station</u>	<u>County</u>
Hayward 4 ESE	Alameda
Upper San Leandro Filter	Alameda
Walnut Creek ENE	Contra Costa
Novato 8 WNW	Marin
Saint Helena 4 WSW	Napa
San Francisco WSO AP	San Francisco
San Francisco WSO CI	San Mateo
San Jose	Santa Clara
Fairfield 3 NNE	Solano

For the orginal application of ABMAC, each modelling unit was characterized as one of three types: (1) natural or protected, (2) nonurbanized but developable and (3) existing urban. For this study, greater resolution was obtained by using land use data available at ABAG from the 1980 census. Census data were available by tract, identifying areas devoted to the following land uses:

o Undeveloped acres specifying:

- unavailable acres (parks, inland waters, urban reserves and zoned open spaces)
- available acres (not presently occupied by structures but zoned for development)

- o Developed acres specifying:

- residential (single or multi-family housing)
- commercial/industrial (retail stores, schools, hospitals, government buildings, offices, manufacturers, etc.)
- streets

Census tract land use data was compiled into three categories: residential, commercial/industrial, and undeveloped. Undeveloped included areas both available and unavailable to development. Streets and highways were not included as a separate land use, but added proportionately to the residential and commercial/industrial classification following Formulas III-3 and III-4.

$$R_t = R_c + \frac{(R_c)}{(R_c + C_c)} (S_c) \quad (\text{III-3})$$

$$C_t = C_c + \frac{(C_c)}{(R_c + C_c)} (S_c) \quad (\text{III-4})$$

Where: R_t = Total residential area in census tract
 R_c = Residential area specified in census tract data
 C_t = Total commercial/industrial area in census tract
 C_c = Commercial/industrial area specified in census tract data
 S_c = Streets and highways specified in census tract

A correspondence table was developed by overlaying census tract maps with modelling unit maps. Where census tracts were not entirely contained within a single modelling unit, the tracts were divided on the basis of whether 1/4, 1/2, or 3/4 of a tract should be assigned to a particular unit. The land use distribution within a fraction of a unit was assumed to be identical to the distribution for the unit as a whole. The land area devoted

to each use within each modelling unit was compiled as the composite of the areas from the contained census tracts.

While this procedure was fairly coarse in assigning census tracts to appropriate watersheds, the significance of errors was minimized by two factors. First, large census tracts, in which area designation only to the nearest 1/4 of the tract could result in relatively large errors in assigning land to appropriate watersheds, were largely undeveloped. Since undeveloped areas contribute relatively little of the oil and grease to a watershed, assignment of area to a neighboring watershed would result in little difference to overall calculations of oil and grease loading. Second, assignment of land to a neighboring watershed would impact calculated values of oil and grease loading only as a function of the difference in rainfall between the two watersheds. Since neighboring watersheds usually have similar rainfall, inaccuracies caused by imprecise assignment of census tract will result in little difference to calculation of oil and grease loading.

CALIBRATION/VERIFICATION

The data obtained in the sampling program are used to verify coefficients developed in the Richmond study (Stenstrom et al. 1982, 1984) and recalibrate the model. In addition to precipitation and land use data, the model requires coefficients describing pollutant concentrations and the ratio between runoff and rainfall. These coefficients were determined in the previous work looking at a single watershed. Since the current study does not include measurement of flow, runoff coefficients determined in this earlier study will be used. New coefficients describing water quality based on the current study are determined, and compared to those previously calculated for model verification. Use of the empirical data to determine these coefficients is shown in Chapter V dealing with modelling results.

Concentrations of hydrocarbons found at the various sampling stations are examined on the basis of land use to determine appropriate coefficients. Thus, the land use in the sampling station watersheds needed to be determined. Since these watersheds were used for model calibration/

verification, more precision was necessary than for determination of land use in modelling units describing the entire region.

Boundaries for each watershed were identified using maps supplied by local water agencies and USGS topographical maps. Maps identifying watersheds were generally available from water agencies in the South and Central Bay. If the sampling point was not at the mouth of a watershed (although location at the watershed mouth was an important consideration in initial sampling site selection), boundaries of the area feeding into the sampling point were determined by making appropriate modifications of watershed maps based on examination of topographical maps and/or through conversation with local water agency personnel. Maps generally were not available defining watershed boundaries in the North Bay, so watersheds were determined through examination of contours on USGS topographical maps. Once watershed boundaries had been clearly defined, the total area within each watershed was determined by planimetry.

Land use was determined on the basis of census tract data as described above when tracts lay entirely within watersheds. However, when only a portion of a tract was within a watershed, the size of that portion was determined by planimetry. Some areas were obviously appropriate to designate as undeveloped. For developed, or partially developed areas, a judgment was made whether the land use was uniform within the entire census tract partially contained in the watershed. This judgment was made using local zoning ordinance maps, street maps, topographical maps, and on-site inspections. If the land use was uniform, the land use distribution within the entire census tract was used to proportion that portion of the tract within the watershed into land use classifications. Thus Formulas III-5, III-6 and III-7 were used to calculate land use for these areas:

$$\frac{(R_t)}{(R_t + C_t + U_t)} A = r_t \quad (\text{III-5})$$

$$\frac{(C_t)}{(R_t + C_t + U_t)} = A = c_t \quad (III-6)$$

$$\frac{(U_t)}{(R_t + C_t + U_t)} = A = u_t \quad (III-7)$$

Where:

- U_t = total undeveloped area in census tract
- A = area of portion of census tract in watershed
- r_t = total residential area in census tract within watershed
- c_t = total commercial area in census tract within watershed
- u_t = total undeveloped area in census tract within watershed

An estimate was made from available maps of the land use of census tracts which did not appear to have uniform characteristics within and outside the watershed. These estimates were made either by assuming the same relative distribution of land use as nearby complete census tracts or by measurement with a planimeter on maps of areas characterized by a specific land use.

SAMPLE SITE CHARACTERIZATION

The land-use and area of the sampling site drainages, as determined using the procedure specified above, is shown on Table III-2. Sampling site locations are shown on Figure II-3. Also on Table III-2 is the linear extent of freeways and highways, included since areas of heavy vehicular use may have a disproportionate effect on hydrocarbons in runoff. Following is a description of each sampling site.

o RICHMOND

The Richmond watershed, containing a variety of land uses, lies within the City of Richmond, Contra Costa County. Oil and grease in runoff from this watershed was the subject of a previous ABAG study (Stenstrom et al. 1982) providing the motivation for this current investigation.

Oil and grease was found in runoff in concentrations as high as 85 mg/l and averaged between 4 and 15 mg/l for sampling stations associated with different land uses.

The sampling station for this study is located at the mouth of the watershed, near the intersection of 32nd Street and Griffin Avenue. At this point, runoff flows through a concrete trapezoidal drainage channel and discharges to San Francisco Bay. Sampling was done with the stainless steel bucket since shoreline access was difficult. Flow was very turbulent during and following a storm, but fairly quiescent during dry periods.

Table III-2. Sampling Site Drainage Land Use

Creek Sampled	Percent Land Use			Total Area (mi ²)	Arterials* (linear mile)
	Residential	Comm/Ind	Undevelop.		
1. Richmond	73	22	5	2.5	0.2
2. Sleepy Hollow	26	0	74	3.1	0.0
3. Sonoma	2	0	98	60.5	0.0
4. Napa	10	3	87	16.9	0.0
5. Temescal	53	13	34	5.9	8.0
6. Glen Echo	51	14	35	.86	0.0
7. Arroyo Viejo	40	12	48	6.3	1.4
8. Elmhurst	58	34	8	3.0	0.0
9. Pine-Galindo	23	5	72	26.4	0.0
10. Castro Valley	56	12	32	4.5	3.3
11. Crandall	44	15	41	1.2	1.5
12. Guadalupe	22	4	74	60.0	7.7
13. Calabazas	56	14	30	14.5	9.1
14. Matadero	5	2	93	2.9	1.2
15. Colma	38	21	41	9.8	7.5

*Freeways and highways

- o SLEEPY HOLLOW CREEK

Sleepy Hollow Creek drains a canyon in San Anselmo, Marin County. Low density single family residences characteristically are found on the canyon floor, with the hillsides largely undeveloped. The main thoroughfare in the watershed, Butterfield Road, parallels the creek, with much of the housing along this street.

The samples were taken from the creek (running along the east side of Butterfield Road) just south of Carlson Court. The creek has not been channelized, appearing to follow its natural course.

Sampling was done primarily by inserting the sampling bottles into the creek. However, the creek was usually not deep enough to fill the bottles, so they had to be topped off by bailing from a steel bucket. Sampling was done just downstream of some small riffles to maximize collection of a mixed sample. During periods of heavy runoff, flow was fairly turbulent and well mixed. During periods of low runoff, flow was not well mixed.

- o SONOMA CREEK

Sonoma Creek was sampled just north of Boyes Springs, Sonoma County, upstream of any major development. The sampling point is downstream of Aqua Caliente Road, on the east bank. The drainage basin is largely undeveloped with about 4% of the watershed containing some housing.

Sampling was done by inserting the sampling bottles into the water from the shore just downstream of a riffle. Flow appeared sufficiently turbulent to result in collection of a well mixed sample.

- o NAPA CREEK

The sampling site on Napa Creek is downstream of a substantial portion of the City of Napa, Napa County. The sampling station is located

under the bridge on Jefferson Street, on the south bank, at A Street, in the City of Napa. Development in Napa is largely residential with some commercial areas. The majority of the watershed, upstream of the City of Napa, is undeveloped.

Sampling was done primarily by inserting the sampling bottles by hand into the creek. However, depth was not always sufficient to fill the bottles, so a steel bucket had to be used to complete sampling. Flow was often fairly quiescent, although some minor riffles were present causing some mixing.

- o TEMESCAL CREEK

Temescal Creek was sampled near its mouth in Emeryville, Alameda County. The sampling station is located off of 53rd Street, near Horton Street, where the underground drainage pipe emerges under the Southern Pacific Railroad tracks. The area near the sampling point is largely commercial. Moving upward in the watershed, the land use shifts from residential/commercial, to mixed residential, and finally to areas of low density residential and open space in the East Bay hills.

Samples were taken primarily by inserting the bottles by hand into the water. Occasionally, during periods of high flow, the sampling bottles could be submerged completely, but a bucket usually had to be used to complete filling of the bottles.

- o GLEN ECHO CREEK

The smallest drainage area examined in this study was at Glen Echo Creek in Oakland, Alameda County. The sampling site is southeast of Broadway and southwest of Highway 580, in a small park bordered by Richmond Boulevard. Most of the general neighborhood has been developed commercially, intermixed with some single and multi-family housing. The street surrounding the sampling site, Richmond Boulevard is residential. In the upper portions of the watershed, there is a mix of

residential and undeveloped areas, with much of the watershed very hilly and difficult to develop.

Samples were taken where the creek discharges from a culvert under the freeway bridge. Sampling bottles were submerged in the creek when the water was sufficiently deep, with complete filling usually requiring the use of a steel bucket. Flow was rarely sufficiently turbulent to ensure a well mixed sample.

- o ARROYO VIEJO

Arroyo Viejo drains a watershed in Oakland, Alameda County. The sampling site is from a bridge on Snell Street, between 75th and 76th Avenues. While the area surrounding the sampling site is mixed industrial and residential, the upstream area in the hills is largely a mixture of residential and undeveloped.

At the sampling point, the creek is in a concrete channel. Sampling was done completely with a steel bucket since the creek bank is not readily accessible. The channel is broad and flat, so there was no opportunity to collect a sample from a turbulent area except during periods of very high flow.

- o ELMHURST CREEK

The Elmhurst Creek drainage in Oakland is the next drainage to the south of the Arroyo Viejo drainage. However, the Elmhurst drainage is substantially more developed, containing a larger percentage of both residential and commercial/industrial area than the Arroyo Viejo drainage. The sampling site is east of San Leandro Boulevard and north of 85th Avenue, where the creek emerges from an underground culvert under the Western Pacific Railroad tracks.

Sampling was done from the bank of the creek by hand. During periods of low flow, the creek discharge was not turbulent.

- o PINE-GALINDO CREEK

This watershed was sampled at the junction of Pine Creek and Galindo Creek in Concord, Contra Costa County. Sampling was done off a bridge on Market Street, just east of Highway 24 and south of Willow Pass Road. The sampling site is located in a busy commercial area. Neighboring areas are largely residential. However, the majority of the watershed is hilly terrain that has not been developed.

At the sampling point, the creek is in a concrete channel. Sampling was done completely with a steel bucket since the bank is not easily accessible. The channel is broad and flat, so there was limited opportunity to sample from a turbulent area. However, when flows were relatively high, discharge in the channel was turbulent.

- o CASTRO VALLEY CREEK

Castro Valley Creek drains a watershed of mixed uses in Hayward, Alameda County. Little heavy industrial activity is present in the watershed, but there is substantial commercial and light industrial activity. The upper portions of the watershed, in the hills, are largely undeveloped. Sampling was done approximately 100 yards upstream from the confluence with San Leandro Creek just east of the Hayward Civic Center.

A mixed sample was obtained by sampling just downstream of a riffle. Water depth was sometimes insufficient to allow complete immersion of the sampling bottles, so a steel bucket was used to complete filling.

- o CRANDALL CREEK

The drainage basin sampled at the Crandall Creek sampling station is relatively small. Land use is mixed, although future plans call for development of much of the open space. The sample was taken just northeast of Newark Boulevard, northwest of Patterson Ranch Road, in Fremont, Alameda County. The sampling point was just above the

discharge of Crandall Creek into the Alameda County Flood Control Channel.

Crandall Creek was sampled in large part by immersing the sampling bottles, although they had to be topped off using a steel bucket. Flow was seldom sufficiently turbulent to appear to be well mixed.

- o GUADALUPE CREEK

This watershed is largely single family housing in the lower portion and undeveloped in the higher, hilly areas. Some light industry is present (electronics firms and fruit packing plants) and some commercial development is located on major thoroughfares. The sampling site is on Almaden Avenue just north of Foxworthy Drive in San Jose, Santa Clara County. This portion of the creek has been channeled and lined with concrete.

A well mixed sample was collected where the stream falls over approximately a two foot step. When the level was relatively low, the steel bucket was needed to complete filling of the sample bottles.

- o CALABAZAS CREEK

The land uses in this watershed area are quite mixed. Over half of the area is residential, most of which is relatively new single family housing. The northern part of the watershed has industrial and commercial uses. Several large commercial developments border Highway 280. The sampling station is located just south of Monroe Street, east of Calabazas Blvd. at Adrian Wilcox High School, in the city of Santa Clara, Santa Clara County.

Sampling was done at a step in the concrete channel, resulting in a well mixed sample. The steel bucket was required for complete filling of the sampling bottle.

- o MATADERO CREEK

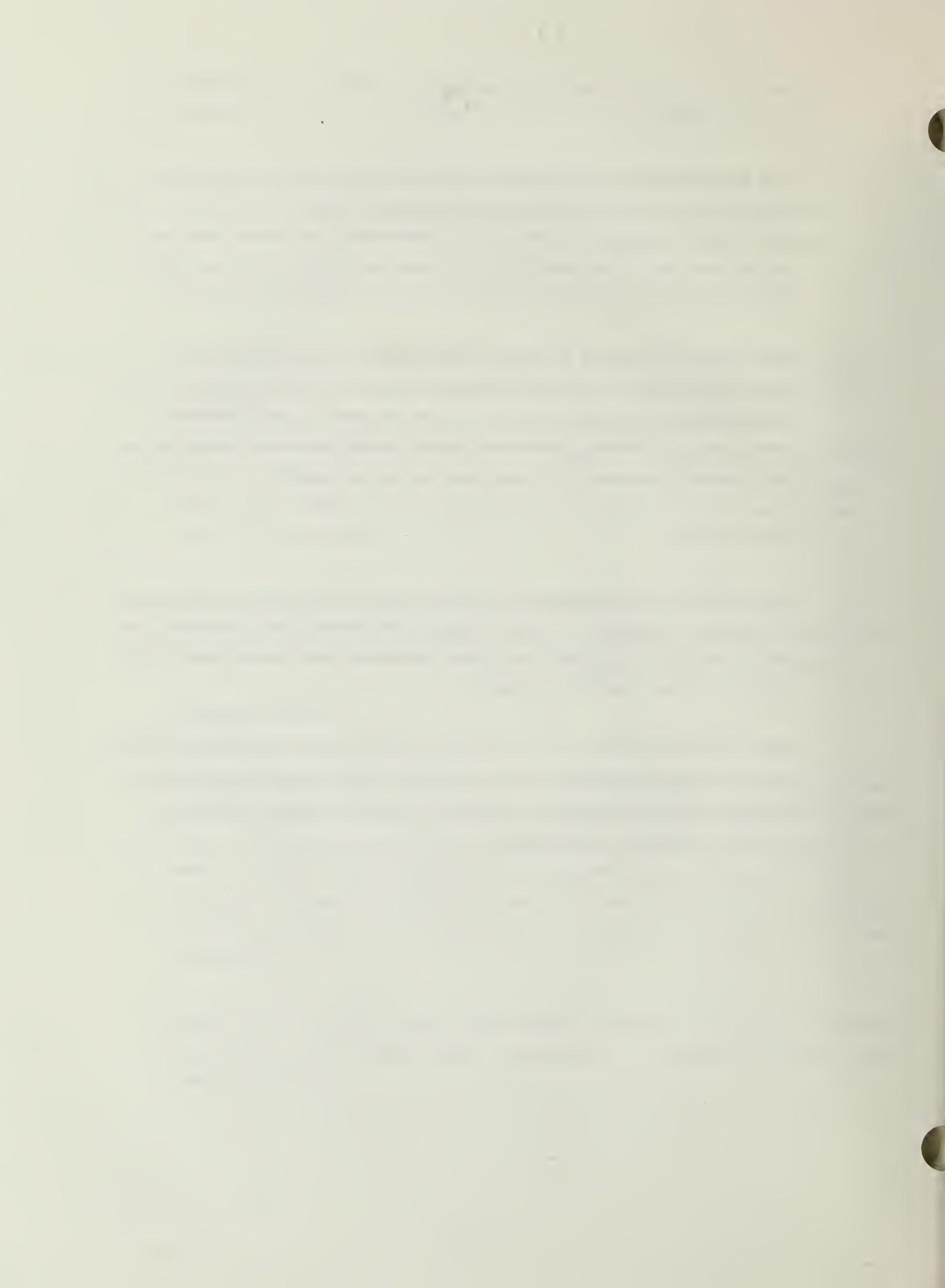
The Matadero Creek watershed is almost entirely undeveloped. Low density residential housing and a physics research laboratory are the only significant structures in the watershed. The creek follows its native course at the sampling point east of Highway 230 and north of Page Mill Road in Palo Alto, Santa Clara County.

Sampling in the creek was done primarily by direct insertion of sampling bottles, although the water level was not consistently high enough to allow complete filling without some topping off from a steel bucket. During periods of fairly low flow, the stream was not sufficiently turbulent to ensure a well mixed sample.

- o COLMA CREEK

Colma Creek has considerable commercial and high density residential development. Also in the watershed are relatively large cemeteries, accounted for as undeveloped land. Sampling was done in West Orange Park in Colma, San Mateo County.

The sampling station is at a point in the concrete channel where the water flows over a small step, allowing collection of a well mixed sample. Shoreline access is difficult, so the entire sample was collected with a steel bucket.



CHAPTER IV

ANALYTICAL RESULTS AND DISCUSSION

INTRODUCTION

Analytical results were evaluated to meet several different objectives. Data from the hydrocarbon analysis were assessed to determine if quantitative and/or qualitative differences were present in oil and grease from different land uses. The nature of these differences were explored to determine if this information is useful in evaluating the toxicity and/or source of hydrocarbons. Relationships between parameters were sought which might prove useful in establishing monitoring programs. Data also were used to calibrate a model predicting oil and grease loading into San Francisco Bay.

Data analyses were done using the statistical analysis program, Statistical Analysis System (SAS 1979). The set of variables shown on Table IV-1 were used in the evaluation.

The raw data for the entire series of runoff samples are shown in Appendix A. A summary of means and simple statistics indicating variability for each station is shown in Appendix B. Results from sampling treated municipal effluent are shown in Appendix C.

Obvious from even a cursory examination is the extreme variability in the data. Shown on Table IV-2 are the means, standard deviation and range of all measured parameters. Analyses were organized around investigations of relationships between water quality and storm phase, and water quality and land use.

Table IV-1. List of Variables and Abbreviations Used For Data Analysis

<u>Watershed Data</u>		
Residential land use (%)		resid
Commercial/industrial land use (%)		comm
Developed land area (resid + comm) (%)		prcomm
Undeveloped land use (%)		undev
Area (acres)		area
Roads (linear miles)		roads
<u>Storm Data</u>		
Storm condition	type	1 = during the active storm period 2 = following the active storm 3 = day after the storm 4 = during the dry season
<u>Water Quality Data</u>		
Total suspended solids (mg/l)		tss
Total suspended solids (mg/l)		tds
pH		pH
Turbidity		turb
Total organic carbon (mg/l)		toc
Total oil and grease (mg/l)		oil_t
Particulate oil and grease (mg/l)		oil_part
Soluble oil and grease (mg/l)		oil_sol
Particulate aliphatic hydrocarbons (mg/l)		palip
Particulate aromatic hydrocarbons (1st extract) (mg/l)		parom
Particulate 2nd extract (mg/l)		ppoll
Particulate 3rd extract (mg/l)		ppol2
Particulate nonelutable (mg/l)		pnelut
Soluble aliphatic hydrocarbons (mg/l)		salip
Soluble aromatic hydrocarbons (mg/l)		sarom
Soluble 2nd extract (mg/l)		spoll
Soluble 3rd extract (mg/l)		spol2
Soluble nonelutable (mg/l)		snelut
Total aliphatic hydrocarbons (mg/l)		talip
Total aromatic hydrocarbons (mg/l)		tarom
Total 2nd extract (mg/l)		tpoll
Total 3rd extract (mg/l)		tpol2
Total 2nd & 3rd extract (mg/l)		tpoll2
Total nonelutable (mg/l)		tnelut
Total particulate hydrocarbons (mg/l)		phydro
Total soluble hydrocarbons (mg/l)		shydro
Total hydrocarbons (phydro + shydro) (mg/l)		hydro
Total nonhydrocarbons (tpoll + tpol2 + tpol12 + tnelut)(mg/l)		tpol
Total hydrocarbon fraction (hydro/oil_t)(%)		fhydro
Aliphatic hydrocarbon fraction (talip/ oil_t) (%)		falip
Aromatic hydrocarbon fraction (tarom/ oil_t) (%)		farom
2nd extract fraction (tpoll/oil_t) (%)		fpol1
3rd extract fraction (tpol2/oil_t) (%)		fpol2
Nonelutable fraction (tnelut/oil_t) (%)		fnelut
Total nonhydrocarbon fraction (tpol / oil_t) (%)		tpol
Total hydrocarbons > C25 / Total hydrocarbons (%)		tratio
Particulate hydrocarbons >C25 / Total hydrocarbons (%)		pratio
Soluble hydrocarbons >C25 / Total hydrocarbons (%)		sratio
Total organic carbon / Total oil and grease		tocrt
Total organic carbon / Total particulate oil and grease		tocrp
Total organic carbon / Total soluble oil and grease		tocrs

Table IV-2. Mean Values and Summary Statistics for all Measured Parameters

<u>Variable</u>	<u>N^a</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Minimum Value</u>	<u>Maximum Value</u>
OIL_SOL	87	2.60	2.42	0.18	10.54
OIL_PART	87	4.10	6.88	0.15	43.72
OIL_T	87	6.71	8.10	0.70	46.91
PALIP	26	3.27	6.01	0.18	28.83
PAROM	26	0.57	0.48	0.18	2.10
PPOL1	22	1.08	2.00	0.09	9.81
PPOL2	22	0.17	0.39	0.00	1.68
PNELUT	26	0.37	0.69	-0.11	2.98
SALIP	26	0.62	0.66	0.09	2.51
SAROM	26	0.37	0.46	0.11	2.44
SPOL1	22	1.21	0.89	0.15	3.19
SPOL2	22	0.42	0.82	0.00	2.83
SNELUT	26	0.32	0.61	-0.14	2.57
TALIP	27	3.77	6.26	0.28	29.70
TAROM	27	0.92	0.80	0.23	3.53
TPOL1	9	2.24	1.73	0.31	5.21
TPOL2	9	1.21	1.59	0.07	4.12
TNELUT	27	0.66	0.99	-0.17	3.29
TRATIO	34	9.06	9.39	0.21	36.87
PRATIO	49	8.92	8.70	0.20	31.30
SRATIO	49	9.18	8.78	0.30	44.00
TSS	78	233.42	687.27	0.99	4630.00
TDS	70	425.03	448.44	62.00	3114.00
PH	78	7.31	0.55	6.00	8.30
TURB	78	28.53	18.63	1.00	50.00
TOC	36	8.14	2.60	3.00	13.00

^a = Number of measurements

STATISTICAL RELATIONSHIPS

STORM CONDITION

Conventional water quality parameters were evaluated to determine if significant differences existed in water quality from each station as a function of storm phase: during the active storm period, following the active storm period, the day after the storm, and during the dry season. This was done to guide further statistical analysis--to help determine the variability within a station in order to compare differences between stations.

Mean concentrations of solids, oil and grease, and mean pH, conductivity and turbidity are shown on Table IV-3. Oil and grease, TSS and turbidity generally declined as the storm progressed from active phase to well after the storm, reflecting declining flow and capability to carry solids. Conductivity, TDS and pH increased, reflecting the lack of fresh flushing water. Analysis of variance indicated that the variation between these parameters was significant as a function of storm phase at the 95 percent level (excepting TSS at 91%), although only accounting for a relatively small fraction of the variability with r^2 between 0.09 and 0.30 (Table IV-4).

Table IV-3. Mean Water Quality Conditions As a Function of Storm Phase

Parameter	Storm Condition			
	During Storm	Following Storm	Day After Storm	Dry Season
Turbidity (NTU)	37.	34.	24.	6.0
pH	7.0	7.3	7.6	7.7
Total Suspended Solids (mg/l)	495.	97.	43.7	11.1
Total Dissolved Solids (mg/l)	191.	516.	513.	738.
Total Oil and Grease (mg/l)	9.7	7.4	4.0	3.0
Soluble Oil and Grease (mg/l)	2.8	3.5	2.4	1.3
Particulate Oil and Grease (mg/l)	6.9	3.9	1.6	1.7
Conductivity	143.	455.	414.	753.

This finding differs somewhat from earlier work in Richmond where oil and grease was not found to vary significantly with any measured storm parameters (Stenstrom et al. 1982, 1984). In this earlier work, measurements were taken only during and immediately following active rain periods; all measurements would correspond to Phase 1 storm conditions in this current study. Thus, it appears that the variation in water quality during a storm follows less of a pattern than the variation between active and later storm periods.

Table IV-4. Statistical Test for Variance: Water Quality Parameters As a Function of Storm Phase

Variable	r^2	F Statistic	Probability >F
Turbidity	0.35	13.30	0.0001
pH	0.26	8.60	0.0001
Total Suspended Solids	0.10	2.85	0.0424
Total Dissolved Solids	0.20	5.60	0.0019
Total Oil and Grease	0.12	3.67	0.0154
Soluble Oil and Grease	0.09	2.21	0.0918
Particulate Oil and Grease	0.12	3.75	0.0141
Conductivity	0.28	9.81	0.0001

Analysis of variance was also conducted to test the hypothesis that the hydrocarbon composition changed as a function of storm phase. Significant differences (at the 95 percent level) generally were not found between the extracted hydrocarbon fractions for different storm phases in terms of either concentration or percentage of total oil and grease (Table IV-5). Thus, while the magnitude of hydrocarbons changed depending on the time from active rainfall, the same pattern could not be seen from individual fractions.

Table IV-5. Statistical Test for Variance: Selected Hydrocarbon Fractions As a Function of Storm Phase

Variable	r^2	F Statistic	Probability >F
Particulate aliphatics	0.17	1.52	0.2380
Particulate aromatics	0.17	1.60	0.2187
Particulate 2nd extract	0.16	1.17	0.3473
Particulate 3rd extract	0.22	1.65	0.2143
Total aliphatics	0.18	1.69	0.1971
Total aromatics	0.24	2.42	0.0919
Total 2nd extract	0.52	7.44	0.0294
Total 3rd extract	0.70	16.26	0.0050
Total non-elutable	0.32	3.65	0.0276
Aliphatic hydro. fraction	0.14	1.26	0.3101
Aromatic hydro. fraction	0.08	0.66	0.5855

LAND USE

Land use data were evaluated to determine if relationships could be established between land use and hydrocarbons. Total and particulate oil and grease showed significance at the 99 percent level of confidence as a function of commercial/industrial land use, although accounting for only a little more than about 1/3 of overall variation. Significance for soluble oil and grease was only at the 69 percent to 78 percent level (Table IV-6).

An analysis of variance was conducted to examine possible relationships between concentrations of specific hydrocarbon fractions and land use. Analyses were conducted in three ways: simple regressions; using randomized block design with phase as the blocking factor; and for each storm phase independently. Significant relationships at the 95 percent level were found only for total hydrocarbons in Phase 1 storm conditions.

Table IV-6. Statistical Test for Variance: Oil and Grease As a Function of Land Use (Storm Phase Is Treated as a Block)

<u>Dependent Variable</u>		<u>Independent Variable</u>		
	<u>Statistic</u>	<u>Undeveloped</u>	<u>Commercial</u>	<u>Residential</u>
Oil-Total	r ²	0.37	0.38	0.39
	F Statistic	2.77	3.19	2.76
	Probability >F	0.0021	0.0006	0.0018
Oil-Particulate	r ²	0.39	0.40	0.40
	F Statistic	3.01	3.40	2.91
	Probability >F	0.0009	0.0003	0.0011
Oil-Soluble	r ²	0.20	0.23	0.23
	F Statistic	1.18	1.49	1.30
	Probability >F	0.3094	0.2252	0.2222

Although the concentration of specific fractions did not correlate well with land use, this relationship was explored further since it may have been an artifact of the extreme variability in the data. The ratio of aliphatic hydrocarbons to aromatic hydrocarbons (talip/tarom) was greater from the more developed watersheds (Elmhurst, Temescal and Colma). As shown on Table IV-7, Elmhurst Creek had almost 10 times as much aliphatic hydrocarbons as aromatic hydrocarbons while the undeveloped watershed had aliphatic and aromatic hydrocarbons in almost equal proportion. Analysis of variance showed that this difference was statistically significant as a function of land use (Table IV-8).

Table IV-7. Percentage of Aliphatic Hydrocarbons to Aromatic Hydrocarbons

<u>Station</u>	<u>Mean</u>	<u>n</u>	<u>Standard Deviation</u>	<u>Minimum Value</u>	<u>Maximum Value</u>
Colma Creek	4.8	5	4.3	1.1	10.9
Elmhurst Creek	9.9	4	11.7	2.8	27.5
Matadero Creek	1.1	5	0.8	0.4	2.2
Sleepy Hollow Creek	1.1	4	0.6	0.5	1.8
Temescal Creek	6.5	6	5.0	0.8	12.3

Table IV-8. Statistical Test for Variance: Ratio of Aliphatic Hydrocarbons to Aromatic Hydrocarbons as a Function of Land Use

<u>Land Use</u>	<u>r^2</u>	<u>F Statistic</u>	<u>Probability >F</u>
Undeveloped	0.24	7.86	0.0096
Residential	0.19	6.15	0.0203
Commercial/Industrial	0.23	7.69	0.0103

This finding of a greater percentage of aliphatic hydrocarbons in runoff from developed watersheds than in runoff from undeveloped watersheds probably reflects inputs of motor oil and diesel fuels composed primarily of aliphatic hydrocarbons.

The ratio of Total Organic Carbon to Oil and Grease was also used to examine possible differences in the organic composition of runoff from different land uses. Both biogenic humic substances and extractable organics contribute to TOC, with only the extractables contributing to measurements of oil and grease. If urbanization results in an increase in

extractable organics (and/or a reduction in humic substances) a relationship would exist between land use and this ratio. If the ratio is low, much of the organic material would be from anthropogenic sources. Analysis of variance confirmed this relationship, with significance apparent between total, soluble and particulate oil and grease, and land use (Table IV-9).

Table IV-9. Statistical Test for Variance: The Ratio of TOC to Oil and Grease As a Function of Land Use.

<u>Dependent Variable</u>	<u>Statistic</u>	<u>Independent Variable</u>		
		<u>Undeveloped</u>	<u>Commercial</u>	<u>Residential</u>
Ratio TOC to Total Oil and Grease	r ²	0.37	0.26	0.37
	F Statistic	19.92	11.89	20.07
	Probability >F	0.0001	0.0001	0.0001
Ratio TOC to Particulate Oil and Grease	r ²	0.21	0.11	0.23
	F Statistic	8.99	4.33	10.20
	Probability >F	0.0051	0.0451	0.0030
Ratio TOC to Soluble Oil and Grease	r ²	0.30	0.33	0.25
	F Statistic	14.75	16.81	11.18
	Probability >F	0.0005	0.0002	0.0020

In addition to examining hydrocarbons fractionated through filtration and extraction procedures, high resolution capillary gas chromatography was used to further identify hydrocarbon groups. Eganhouse et al. (1981) has reported that biogenic sources contribute the odd-numbered hydrocarbons in runoff beginning at C₂₅. To test this hypothesis, the chromatogram areas of the aliphatic fraction for the odd numbered sequence peaks beginning at C₂₅ were added and compared to the remaining areas. This was done for both

soluble and particulate fractions. The percentage of C₂₅ and higher peak area of the total peak area ranged from a high of 44.0 from the Matadero soluble fraction collected in November, 1984, to a low of 0.2 for the Temescal particulate fraction collected in November, 1984. Statistically significant regressions were found between peak ratios and land use, as shown on Table IV-10, supporting the finding that high, odd numbered organics comprise a larger percentage of the overall extracted organic fraction from undeveloped areas than from areas receiving considerable anthropogenic input.

Table IV-10. Statistical Test for Variance: The Ratio of Heavy ($>C_{25}$) Odd Numbered Aliphatic Hydrocarbons (HC) As a Function of Land Use

<u>Independent Variable</u>	<u>Statistic</u>	<u>Dependent Variable</u>		
		<u>Undeveloped</u>	<u>Commercial</u>	<u>Residential</u>
Ratio Soluble HC	r ²	0.66	0.41	0.75
> C ₂₅ to Total HC	F Statistic	90.31	32.72	143.66
	Probability > F	0.0001	0.0001	0.0001
Ratio Particulate HC > C ₂₅ to Total HC	r ²	0.79	0.53	0.88
	F Statistic	181.02	52.44	339.19
	Probability > F	0.0001	0.0001	0.0001
Ratio Total HC > C ₂₅ to Total HC	r ²	0.77	0.44	0.85
	F Statistic	107.75	24.70	183.82
	Probability > F	0.0001	0.0001	0.0001

HYDROCARBON INDICATORS

A stepwise multiple regression was performed to determine the potential for predicting oil and grease levels from the more easily measured water quality parameters of turbidity, residue, and pH. Only pH met the model requirements of significance of at least 0.15, having significance of 0.056 with an F value of 3.78 and r^2 of 0.052. Multiple regression was also conducted using these same parameters for each storm phase, with only a single parameter being significant for each phase at the 0.15 significance level necessary for entry into the model. Thus, common parameters do not appear to provide a useful predictive mechanism to potentially eliminate some of the need for oil and grease monitoring.

Particular attention was given to Total Organic Carbon to determine its potential as an indicator of organic pollution. An analysis of variance, with grouping by storm phase, indicated no significant relationships (at the 95 percent level) between TOC and any of the extracted fractions.

QUALITATIVE EVALUATION

In addition to a statistical analysis of data, a qualitative approach was used to discern differences between samples through examination of chromatographs generated through high resolution capillary gas chromatography. Aliphatic, aromatic and polar fractions were examined independently, with attention focused on detecting differences between characteristic chromatographs of each station reflecting differences in land use.

ALIPHATIC HYDROCARBONS

Chromatographs from the different land use areas had strikingly different aliphatic hydrocarbon distributions. Five hydrocarbon patterns were observed: three major contributing sources were identified, with two unidentified patterns appearing only once in the 69 chromatographs. One or more of the three identified patterns appeared in 68 of the 69 chromatographs. The three identified sources of aliphatic hydrocarbons are

automobile motor oil (Figure IV-1), diesel fuel (Figures IV-2, IV-3), and plant/microbial waxes (Figure IV-4). The two unidentified patterns were n-alkane series centered at C₂₇ (Figure IV-5) and an n-alkane series centered at C₂₃.

Temescal Creek consistently had a chromatographic pattern closely resembling diesel fuel without the lighter fractions (Figure IV-6). Freshly extracted diesel fuel shows an abundance of n-alkanes ranging from 10-25 carbons (Figure IV-2). To check if this apparent loss of the lighter fraction was due to weathering (probably volatilization), a few drops of diesel fuel were aerated with a fine bubble diffuser overnight in two liters of water, with the chromatographic pattern subsequently determined. Much of the 10-15 carbon n-alkane fraction was lost, and the resultant chromatographic pattern (Figure IV-3) was nearly identical to the aliphatic fraction characteristic of Temescal Creek.

Since the Temescal Creek sampling station was located in an heavily industrialized area, it was suspected that the diesel fuel contamination may have come from the immediate vicinity. Subsequent inspection revealed a bus repair yard and several other companies using diesel fuel within a few blocks of the sampling station. A special sampling was conducted during a dry period in April, 1985 to determine if the diesel fuel was from the immediate area. Sampling was conducted at the usual sampling station, and at another point just upstream of the industrial area. The upstream chromatograph revealed that only 14 percent of the integrated peak area could be attributed to diesel fuel, while about 90 percent of the peak area was attributable to diesel fuel at the downstream station. Total concentrations of oil and grease were substantially higher at the lower station, 2.50 mg/l, than at the upper station, 0.87 mg/l. Thus, it appears that a major source of diesel fuel running off into the creek is located within a few blocks of the sampling station.

Runoff collected at the Elmhurst Creek station also drained a heavily industrialized area, but showed a predominance of motor oil rather than diesel fuel. Ten of the eleven chromatographs for the station were nearly identical with the aliphatic fraction of motor oil (Figure IV-7), with the

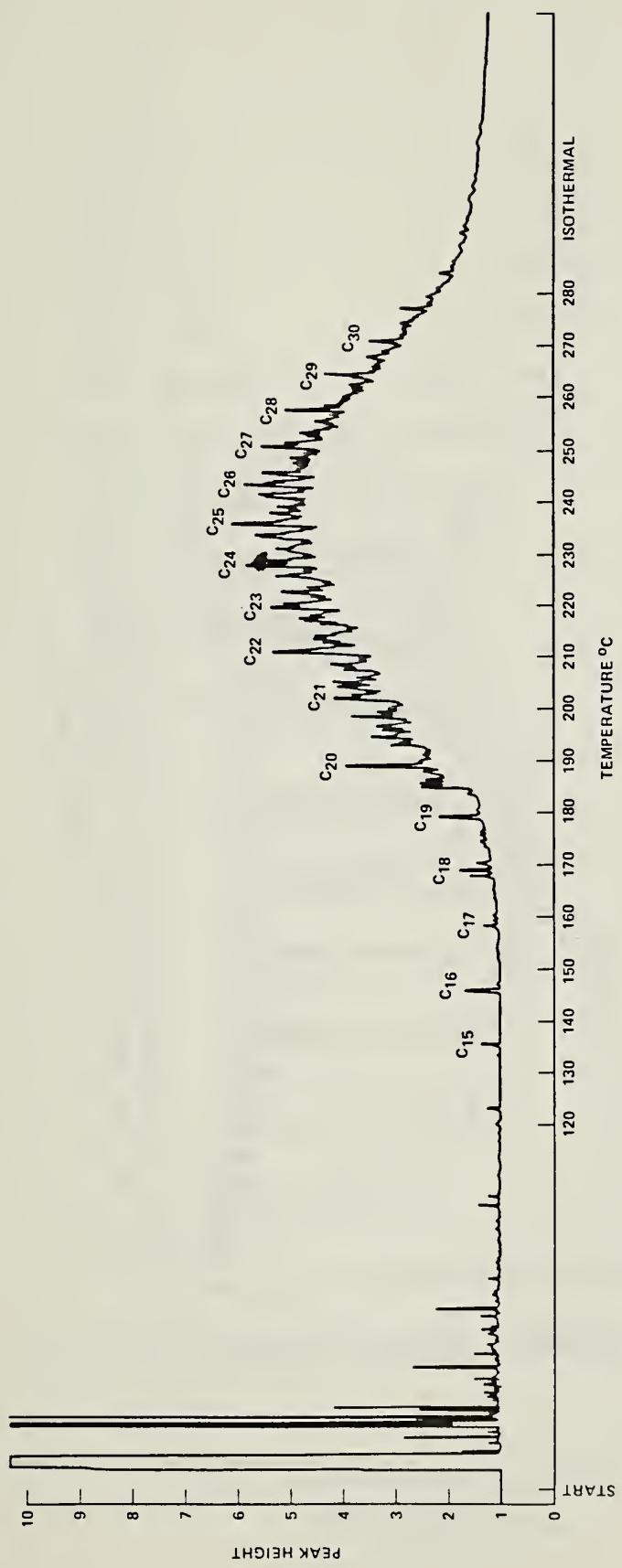


Figure IV-1. Chromatograph of Aliphatic Fraction from Used Motor Oil

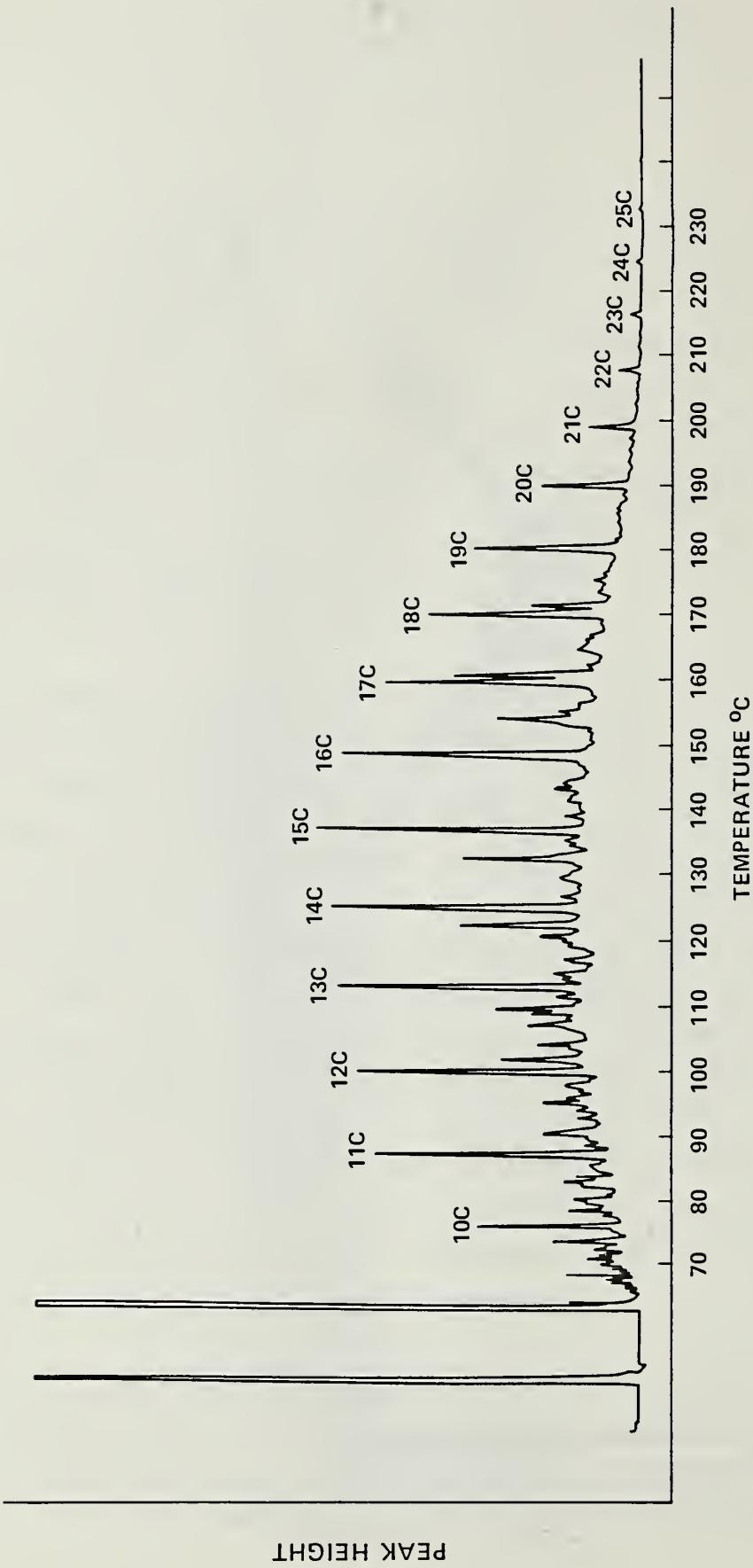


Figure IV-2. Chromatograph of Aliphatic Fraction of Freshly Extracted Diesel Fuel

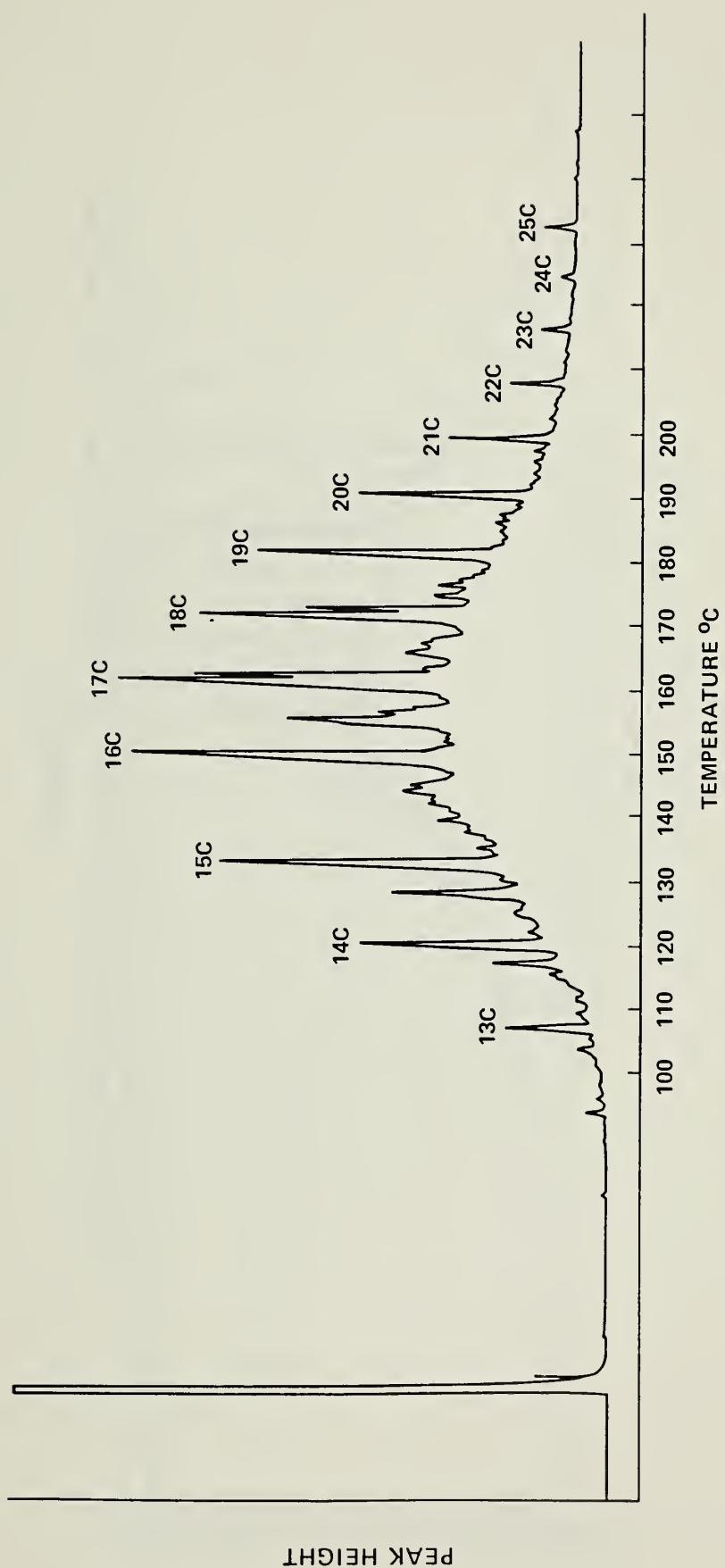


Figure IV-3. Chromatograph of Aliphatic Fraction of Diesel Fuel After Overnight Aeration

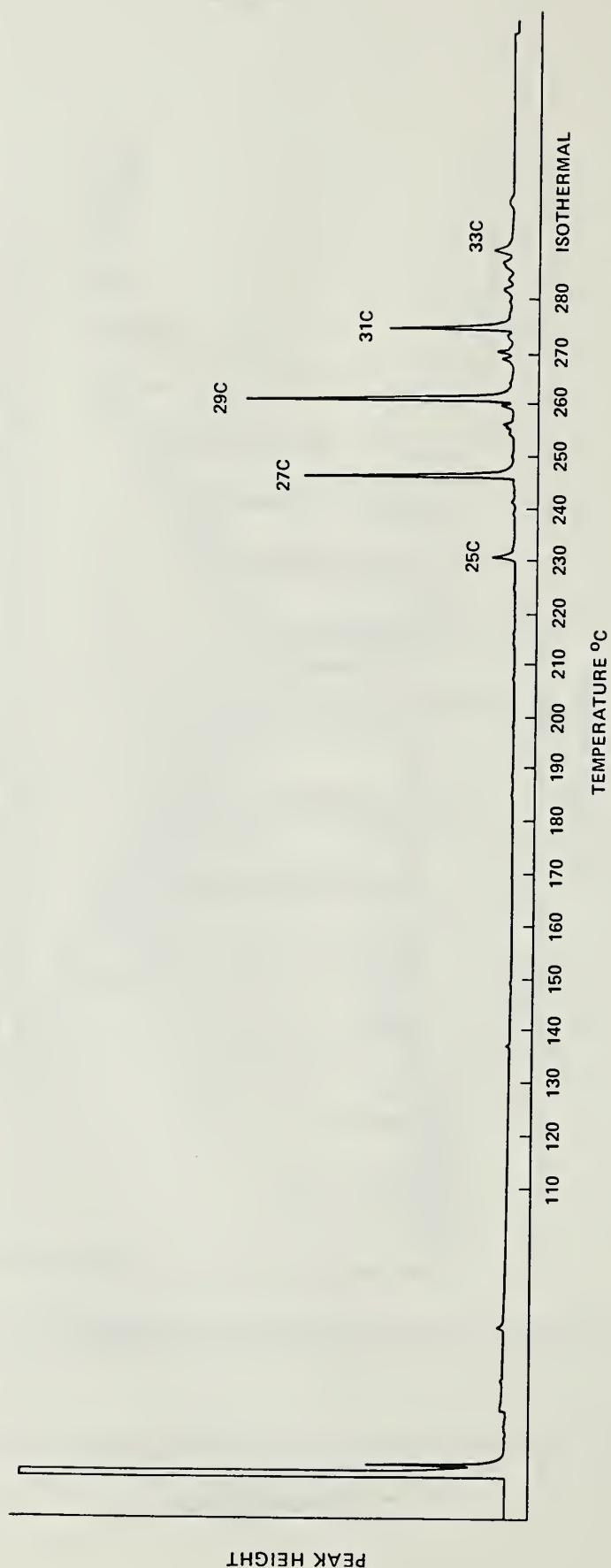


Figure IV-4. Chromatograph of Aliphatic Fraction from Fern Wax

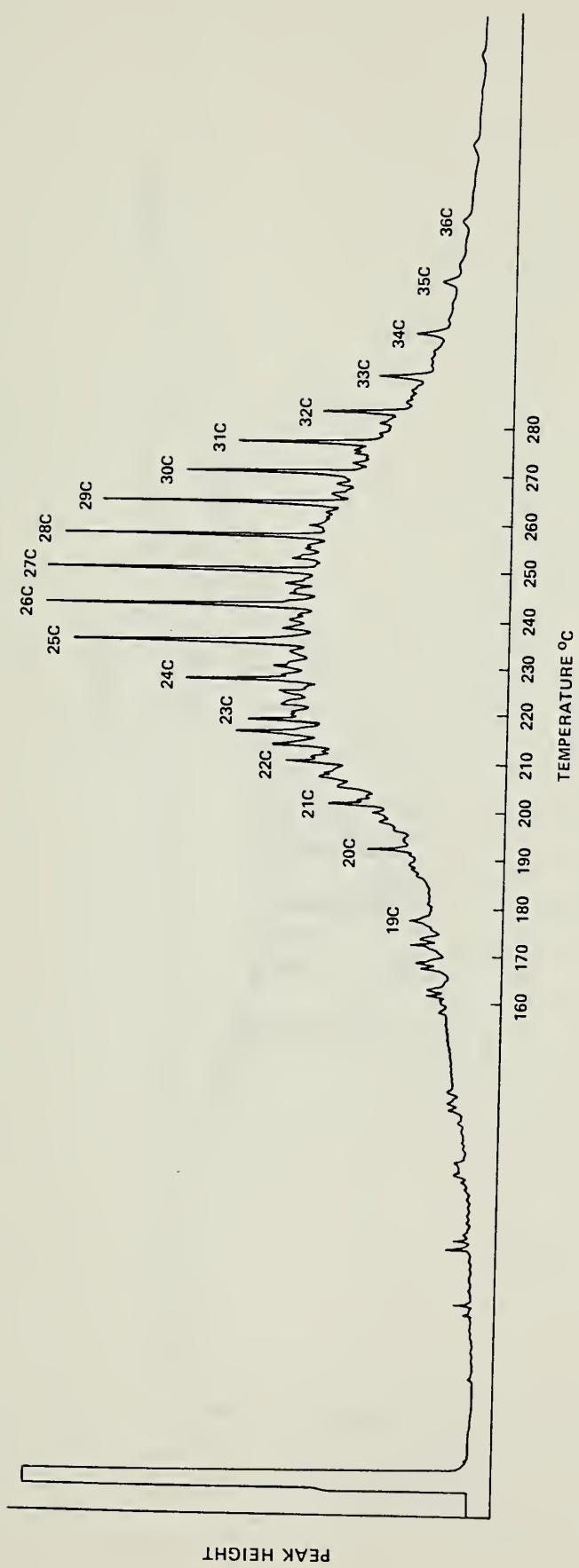


Figure IV-5. Chromatograph of Aliphatic Fraction from Elmhurst Creek Showing Atypical Heavy N-Alkane Series

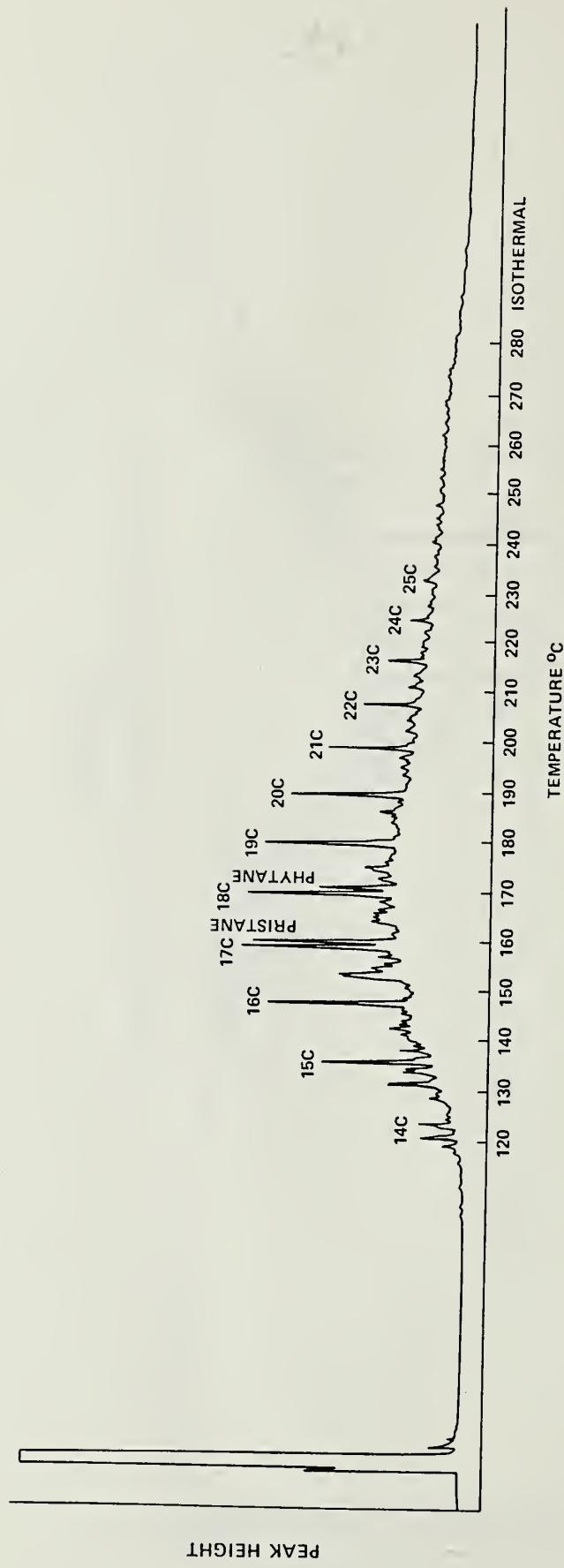


Figure IV-6. Chromatograph of Aliphatic Fraction from Temescal Creek

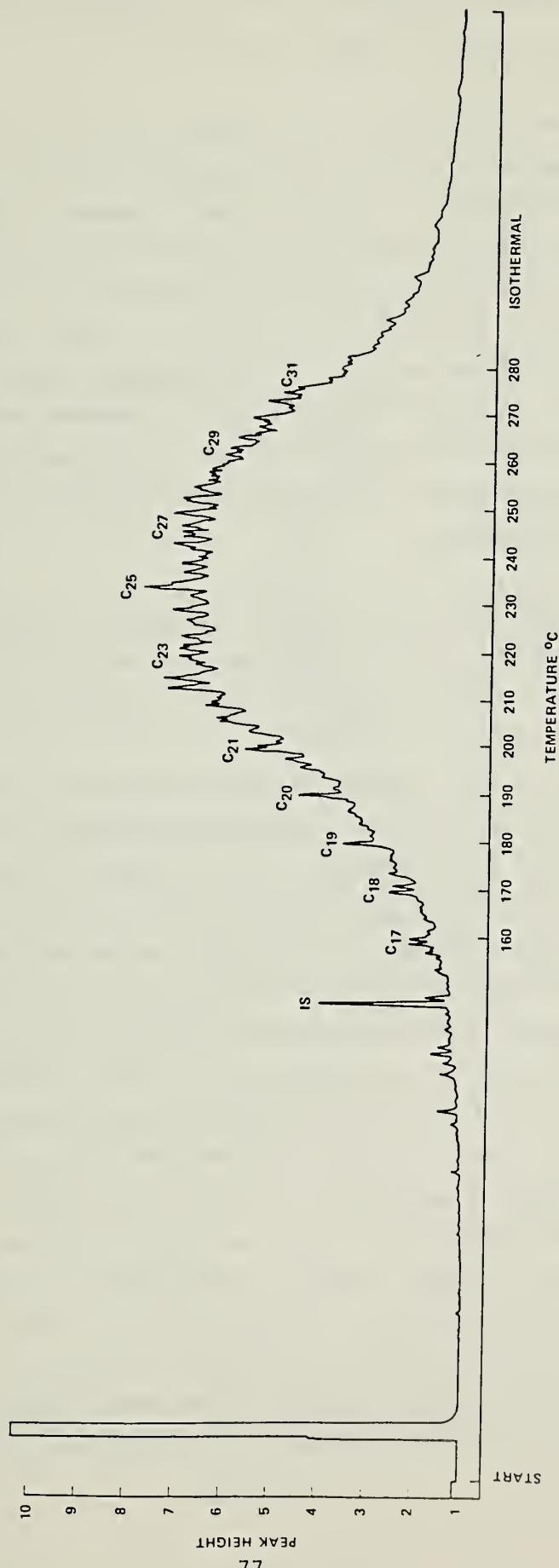


Figure IV-7. Chromatograph of Aliphatic Fraction from Elmhurst Creek

remaining chromatograph containing a heavy n-alkane series in addition to the characteristic motor oil hump (Figure IV-5).

The heavy n-alkane series found from Elmhurst Creek may be of biogenic origin. The presence of high molecular weight n-alkanes ($>C_{24}$) with odd-even predominance (OEP) values greater than 1 suggests the presence of biogenic hydrocarbons, presumably derived from the epicuticular waxes of higher plants (Eglington and Hamilton 1967, Castillo et al. 1967, and Bottari et al. 1972), although Casadevall et al. (1985) observed a similar pattern with the hydrocarbon rich alga Botryococcus brauni. The OEP of this fraction from Elmhurst Creek was 1.25. Eganhouse et al. (1981) identified hydrocarbons fitting this pattern in stormwater from the Los Angeles River, although they never comprised more than 1.67 percent of the total hydrocarbon fraction.

The Colma Creek watershed is also highly urbanized. Evident in the aliphatic fraction (Figure IV-8) is motor oil, diesel fuel, and (suspected) biogenic heavy hydrocarbons (C_{27} , C_{29} , C_{31} and C_{33}).

Sleepy Hollow and Matadero Creeks, draining predominantly undeveloped watersheds, showed essentially the same chromatographic patterns (Figures IV-9, IV-10). Diesel fuel and motor oil was frequently observed, along with a heavy n-alkane series. The heavy n-alkane series was most likely attributable to plant leaf waxes or microbial secretions and usually accounted for 10-40 percent of the observed aliphatic hydrocarbons. The heavier petroleum fractions, transmission fluid and motor oil, have very low amounts of heavy n-alkanes (Hoffman et al. 1984, Dell'Aqua et al. 1975) and are unlikely to contribute to this heavy n-alkane envelope. The heavy n-alkane series was found to usually be centered at C_{29} and showed low amounts of even numbered paraffins (C_{26} , C_{28} , C_{30} and C_{32}). Since several investigators have indicated that C_{29} and C_{31} are the most abundant biogenic n-alkanes, and that the OEP is greater than 1 for biogenic n-alkanes (Eglington and Hamilton 1960; Castillo et al. 1967; Bottari et al. 1972; and Casadevall et al. 1985), the heavy n-alkane series from these creeks appear to be of biogenic origin. More than 70 percent of the observed aliphatics in both Sleepy Hollow and Matedero Creeks were

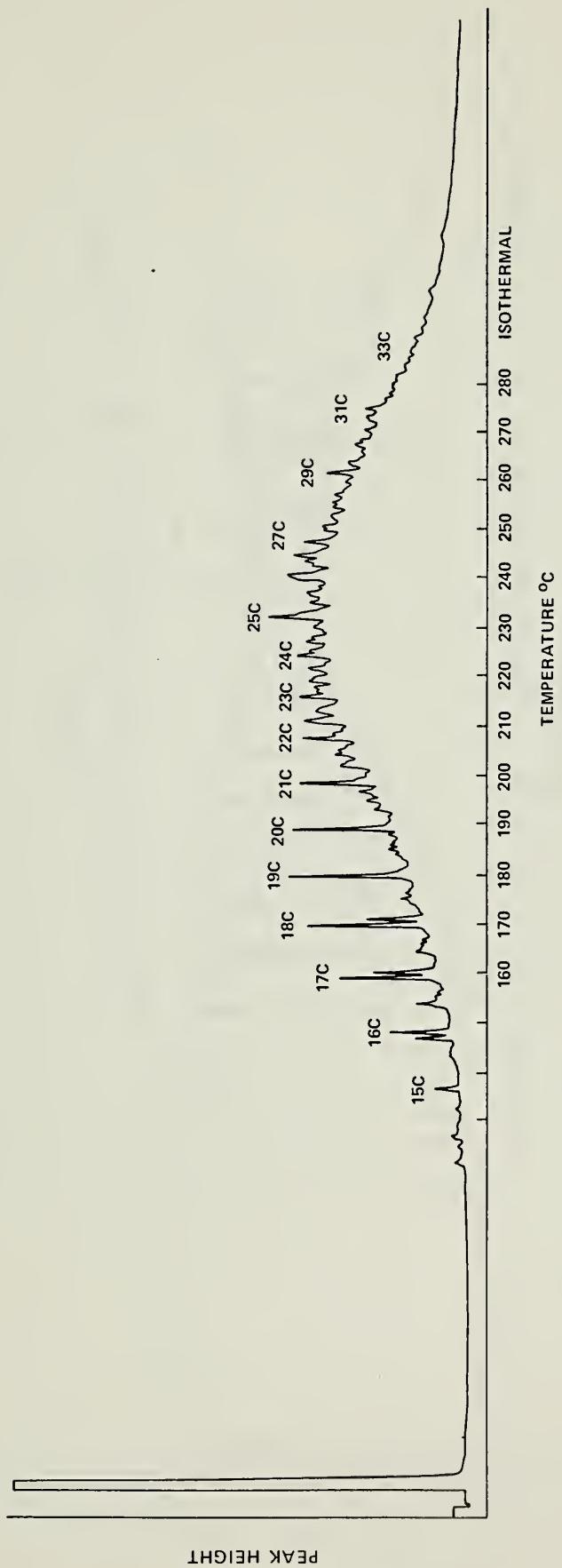


Figure IV-8. Chromatograph of Aliphatic Fraction from Colma Creek

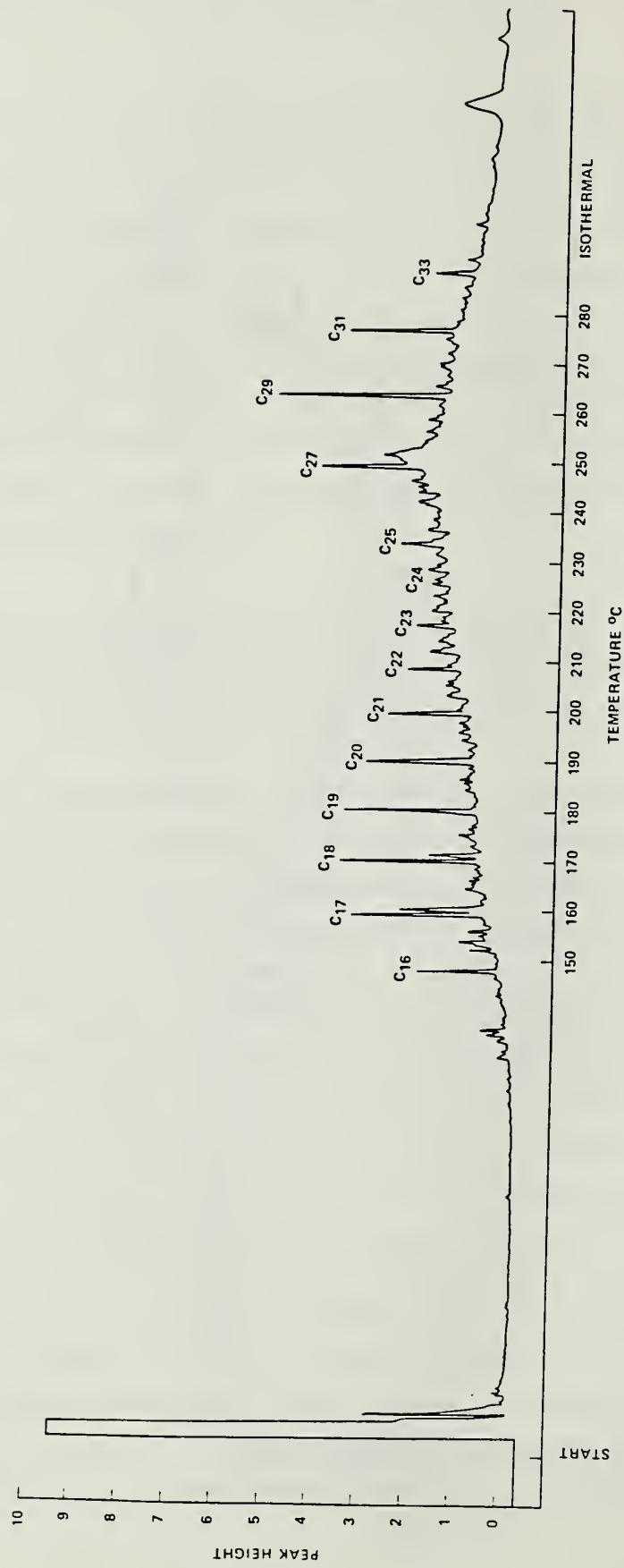


Figure IV-9. Chromatograph of Aliphatic Fraction from Sleepy Hollow Creek

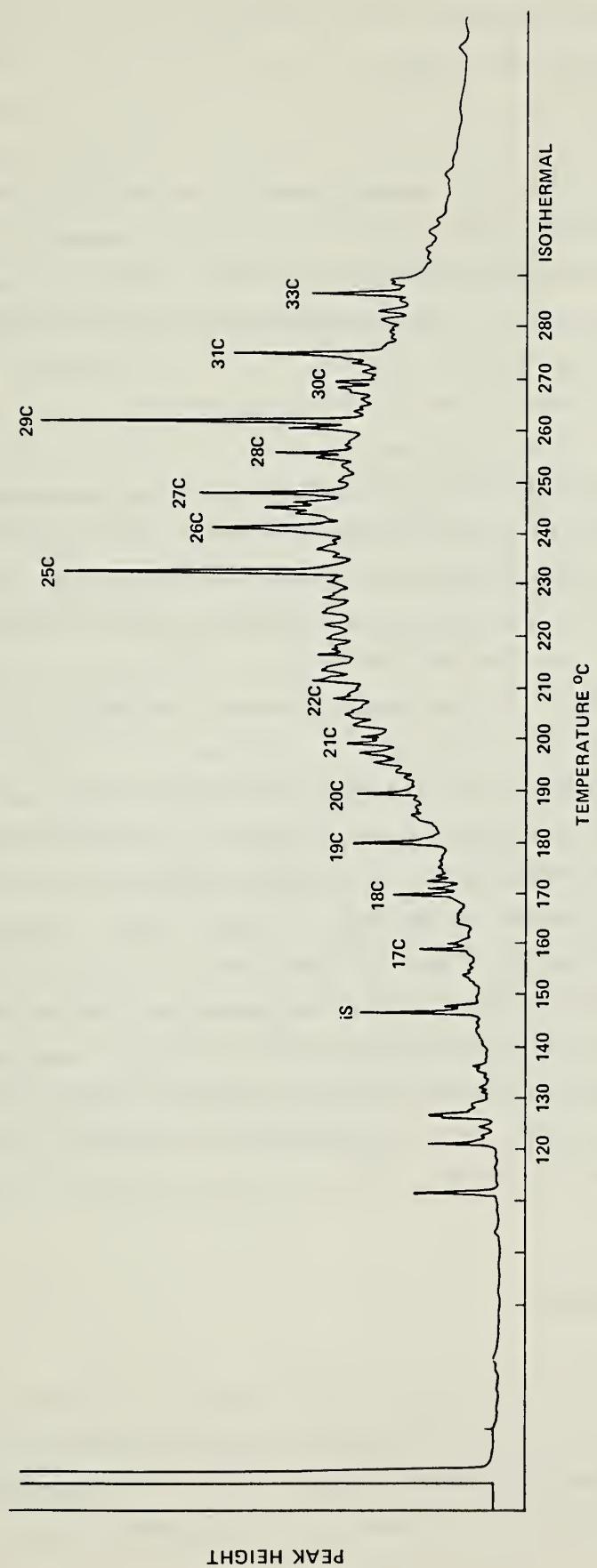


Figure IV-10. Chromatograph of Aliphatic Fraction from Matadero Creek

attributable to anthropogenic sources despite the low levels of urbanization in the watersheds.

Hourly samples were collected for a single storm event from Elmhurst Creek and Sleepy Hollow Creek to investigate hydrocarbon distribution as a function of time during the storm event (Phase 1 storm). Eganhouse et al. (1981) observed a shift in hydrocarbon distribution from unimodal centered at C₂₃ during the early storm to a bimodal distribution during the later storm hours. They also observed more heavy hydrocarbons associated with the particulate fraction than with the soluble fraction.

Conditions did not change significantly in the chromatographs of the hourly monitored Sleepy Hollow storm event; the only observed difference was an increase in the heavy hydrocarbon load in the 13:30 p.m. soluble fraction (Figure IV-5). Only traces of the n-alkane series were found in the particulate fraction from the same sample. Otherwise, the soluble and particulate fractions looked fairly similar throughout the storm.

In 22 of the 34 observations the soluble fraction contained more biogenic hydrocarbons than the particulate fraction. This was somewhat surprising since biogenic hydrocarbons are very water insoluble due to their high molecular weight, unlike motor oil and diesel fuel. This may be due to biogenic hydrocarbons not being flushed from roads and parking lots with particulate dirts (not pre-adsorbed to particles), while the biogenic hydrocarbons had to be desorbed from plant material into the runoff waters. This could account for the soluble fraction containing greater percentages of biogenic hydrocarbons than the particulate fractions. Additional research is needed to provide a better understanding of the reason for this apparent anomaly.

AROMATIC HYDROCARBONS

The benzene elutable fraction has been termed the aromatic fraction because it is the fraction in which polynuclear aromatic hydrocarbons will elute. Numerous other compounds (alkyl benzenes, cyclic hydrocarbons > C₂₀ and heavy polyunsaturated hydrocarbons) will also be collected in this fraction

and the majority of these compounds were not identified. The intent in examining this fraction was to test for the presence of some common polynuclear aromatic hydrocarbons (PAHs) (listed in Table IV-11) and to compare the fingerprint appearance of various land use fractions.

Nearly all of this fraction had a large complex eluting at 250 C (Figure IV-11). Some had a complex eluting at 160 C of which anthracene was a constituent. The most commonly identified PAHs were anthracene, fluoranthene, indenol pyrene, and benzo-perylene. Chrysene was detected on two occasions.

No clear differences in the chromatographs were observed in samples from different land use areas, except that Elmhurst Creek frequently (7 of 8 samples) did not show the 250 C complex (Figure IV-12). This late eluting complex was present in all of the Sleepy Hollow and Matadero and most of the Colma and Temescal second fraction chromatographs.

Since the late eluting complex seems to be associated with low urbanization, it may be inferred that it represents a biogenic source. Further support for this assertion comes from the work of Battari et al. (1972) who isolated several C₂₆ - C₃₀ plant terpenes as a silica gel benzene eluate (their first fraction was collected with petroleum ether). The retention time of the 250 C mixture is similar to the C₂₆ - C₃₀ n-alkane retention times. This complex showed some carryover (up to 25 percent) in the aliphatic fraction, but was primarily elutable by benzene. This may indicate that it is a cyclic aliphatic with some unsaturation (possibly plant terpenes). Without mass spectral or GC retention time matches this must be regarded as tentative.

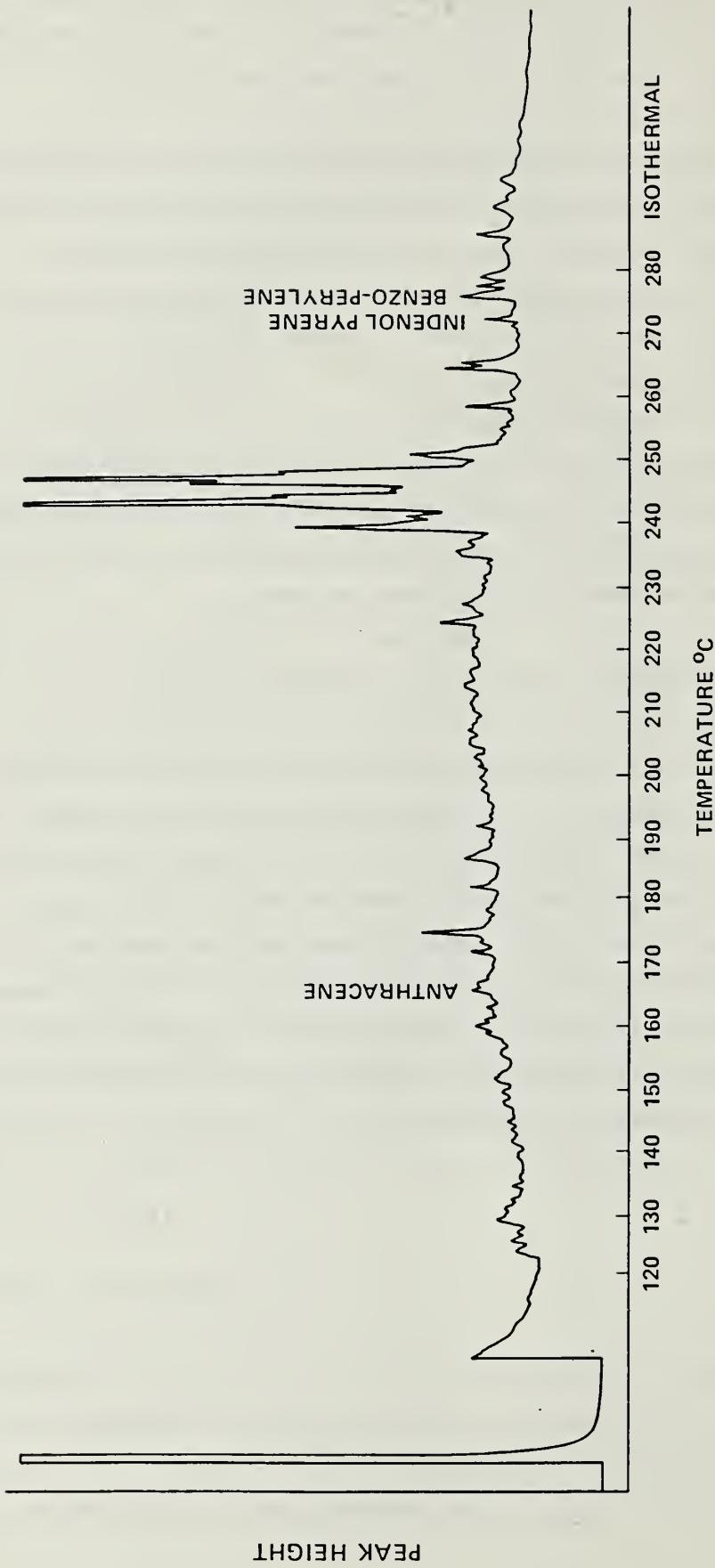


Figure IV-11. Chromatograph of Aromatic Fraction from Sleepy Hollow Creek

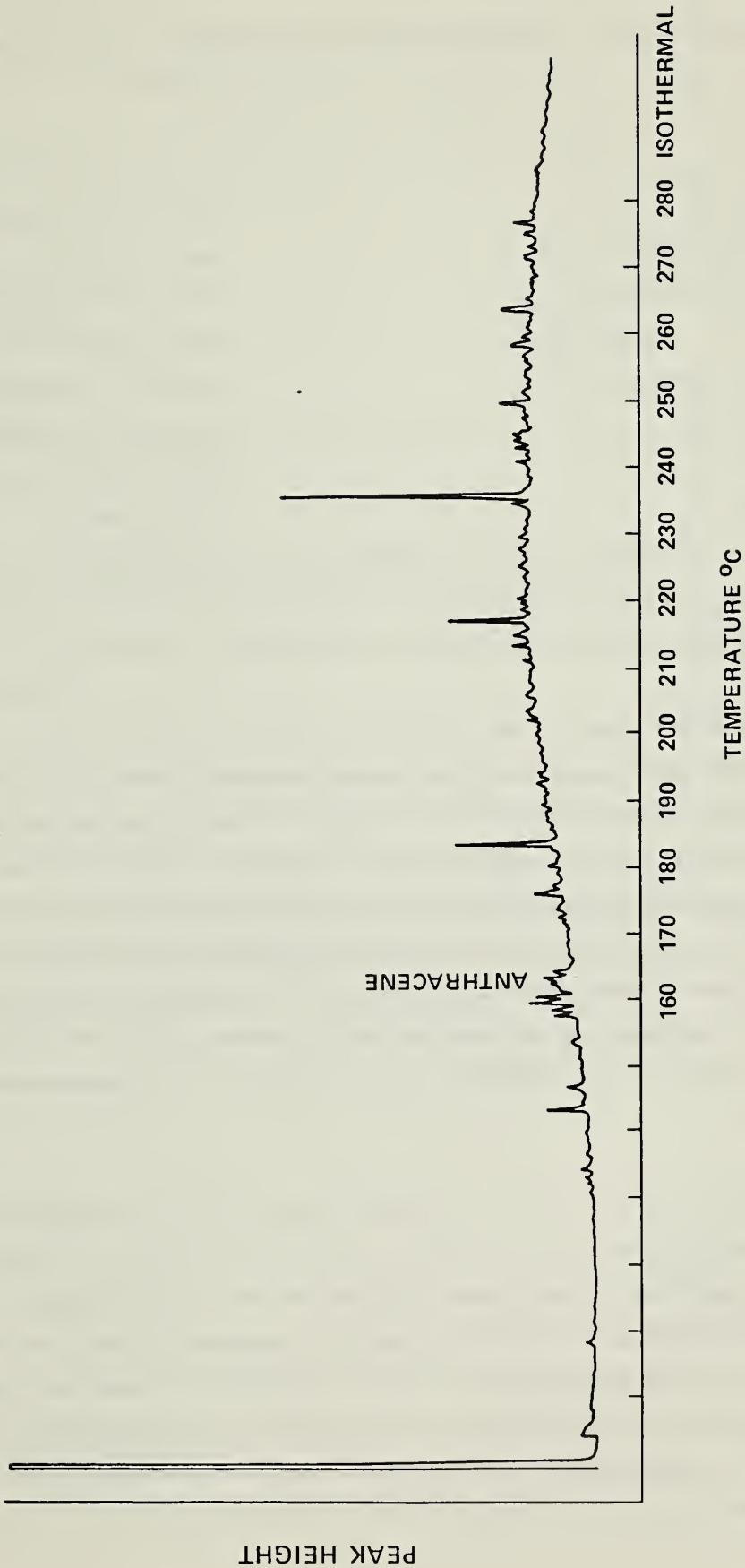


Figure IV-12. Chromatograph of Aromatic Fraction from Elmhurst Creek

Table IV-11 . Polynuclear Aromatic Hydrocarbons Tested For
in Benzene Extracted Fraction

napthalene	benzo (a) anthracene
acenaphthylene	benzo (b) fluoranthene
acenaphthene	benzo (k) fluorane
fluorene	benzo pyrene
phenanthrene	indenol (1,2,3,a) pyrene
anthracene	dibenz (ah) anthracene
pyrene	benzo (ghi) perylene
chrysene	fluoranthene

POLAR FRACTIONS

The chloroform/methanol elute, called the polar fraction due to its binding properties with silica gel, is the fraction which gives the extractable oil and grease its noted yellowy brown color. It contains any organic compound with a polar functional group such as an alcohol, carboxylic acid, phenolic, amine or ketone. Sixty five reference polar compounds were used for identification. The goal of the chromatographic analysis was to identify as many compounds as possible and to fingerprint any differences in the chromatographs representative of different land uses. Those polar compounds tentatively identified by GC retention time matches are listed on Table IV-12.

Polar compounds are difficult to analyze because of their poor resolution by gas chromatography. It is common practice to sylilate (Casadevall et al. 1985), acetylate (Coutts et al. 1979) or react the compounds with diazomethane (Fales et al. 1973) to render a non-polar derivative which is more amenable to chromatography. A polar carbowax column was used directly in this study because of excellent resolution for alcohols and phenols, and because of the large number of analyzed samples.- However, acids were not well resolved.

Table IV-12. Polar Compounds Tentatively Identified by GC Retention Time Matches

octanol	3, 5, xylenol
nonanol	3, 4, xylenol
tridecanol	ethyl phenol
tetradecanol	2, 3, 5 trimethyl phenol

A third fraction chromatograph from Elmhurst Creek is shown on Figure IV-13. Elmhurst Creek shows a very large concentration of tetradecanol and two other unidentified compounds (19.02 and 21.91 retention times).

Overall, the polar chromatographs showed somewhat consistant patterns for a given station but a varied appearance among the five analyzed stations. The lack of any positive identification of specific compounds prevents any conclusion to be made regarding the origins of these polar organics. The dissimilarity of the chromatograms, however, may indicate that polar compounds could potentially be used as an indicator of land use in the same manner as hydrocarbon distribution patterns.

SUMMARY OF FINDINGS

Analyses of typical indicators showed that water quality changed significantly following a storm, with oil and grease peaking during active rainfall and decreasing to lowest levels during the dry season. Specific hydrocarbon fractions did not follow this pattern, either in terms of concentration or percentage of total extractable organic load. This suggests that while concentrations of oil and grease decrease with

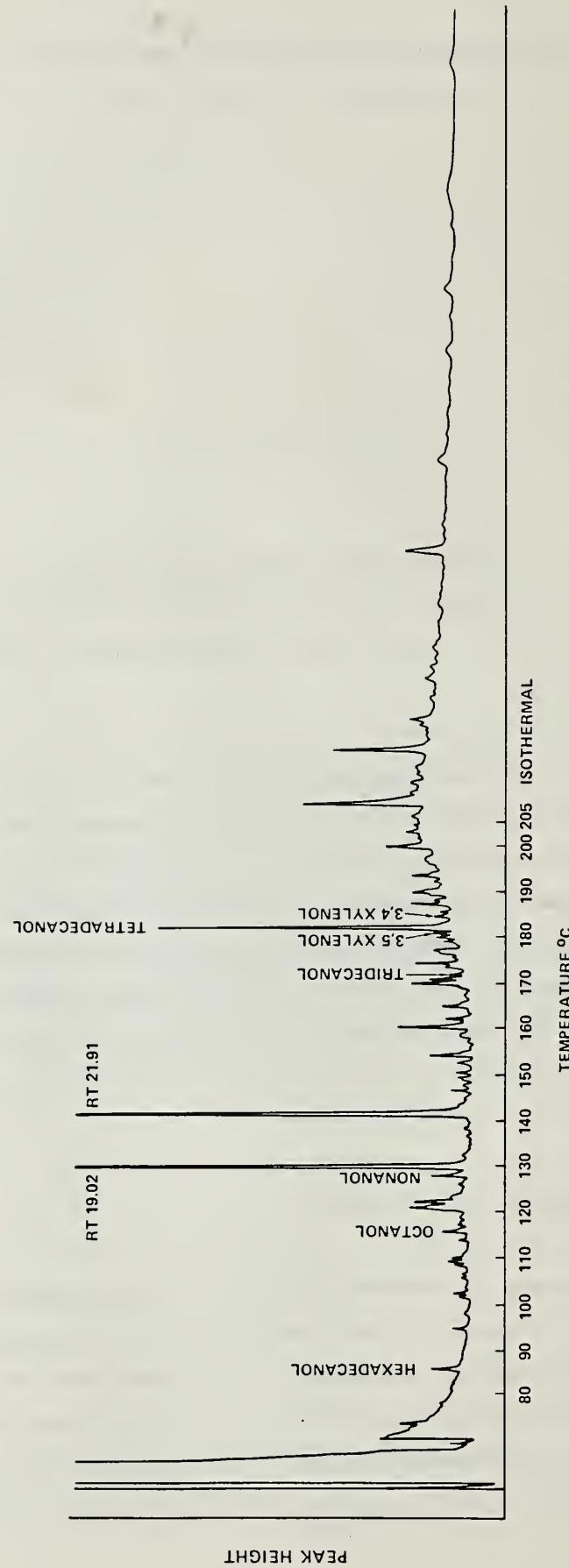


Figure IV-13. Chromatograph of Third Fraction from Elmhurst Creek

decreasing flow, the nature of the material does not change following an observable pattern.

Land use correlated significantly with oil and grease concentrations, although accounting for relatively little of the overall variability. Examination of a scattergram of land use versus oil and grease illustrates the tremendous variation in concentration at individual stations, even during the same type of storm condition. Watersheds that were largely undeveloped generally had uniformly low concentrations, while more developed watersheds had both relatively low and relatively high concentrations. This may indicate that rather than urbanization resulting in a high background level of oil and grease, urbanization results in a greater chance for a substantial input to be released in the watershed.

The predominant sources of hydrocarbons found in watersheds remains relatively consistent regardless of land use. For example, the Sleepy Hollow watershed had no commercial areas and was 76 percent undeveloped; however, nearly 85 percent of the aliphatic hydrocarbons appeared attributable to motor oil and diesel fuel pollution. Similarly, the Matadero Creek watershed was 93 percent undeveloped yet nearly 75 percent of the aliphatics appeared attributable to anthropogenic sources. Thus, even minimal watershed developments appear to result in a significant increase in organic pollution.

A greater percentage of aliphatic hydrocarbons to aromatic hydrocarbons was found in runoff from developed watershed than in runoff from undeveloped watersheds. This difference probably reflects higher loading from motor oil and diesel fuel.

The ratio of TOC/oil and grease relates significantly to land use. Both the biogenic humic substances and the extractable organics contribute to TOC, with urbanization resulting in an increase in extractable organics and a decrease in humics. Thus, the source of oil and grease in a watershed could be investigated by examining this ratio. Preliminary results indicate that a ratio no more than 6 indicates moderate urbanization, although further work is needed for verification. However, in most cases

where levels are elevated sufficiently to warrant an investigation of sources, most of the input will be anthropogenic.

Easily measured water quality parameters did not serve as adequate indicators of oil and grease. Examination of gas chromatographs of organics extracted following oil and grease techniques; however, gave valuable information concerning the nature of oil and grease in runoff. Predominant sources of aliphatic hydrocarbons were diesel fuel and automotive oil. Plant/microbial waxes were also identified. The infrequent occurrence of extracted organics other than those routinely found suggests that they are caused by a single event, and suggests that identification of the unusual material could be used to investigate its source.

CHAPTER V

MODEL RESULTS

INTRODUCTION

Previous work has indicated that loading from local non-point sources through surface water runoff is a significant contributor of pollution to San Francisco Bay. Russell et al. (1982) predicted that by the year 2000 about 40 percent of the suspended solids, 16 percent of the BOD and 36 percent of the heavy metals entering the Bay would come from local runoff. Similar work has heretofore not been done for oil and grease. However, previous work looking at a single watershed in the region (Richmond) has indicated that concentrations of oil and grease in runoff entering the Bay are often much higher than allowed for point sources (Stenstrom et al. 1982, 1984). Thus, the potential for significant oil and grease loading from runoff is high.

An important consideration in using this model is that oil and grease is not a single compound uniformly affecting the environment. As discussed previously, a variety of chemicals with substantially different toxicities all are measured by oil and grease tests. Analyses of specific hydrocarbon fractions did not indicate specific fractions which would be of greater utility for modelling purposes, more indicative of organic pollution. Therefore, the oil and grease modelling still serves as the best approach to gain an understanding of the relative contribution of hydrocarbons from different land uses, and to compare loading from surface runoff with other inputs.

Using the ABMAC model (described in Chapter III) with the data collected for this study (described in Chapter IV) and results from the previous study in Richmond, oil and grease loading into the Bay is estimated for current conditions and predicted for future scenarios.

CALIBRATION

As discussed in Chapter III, the ABMAC model is calibrated using coefficients describing the runoff to rainfall ratio and oil and grease coefficients as a function of land use. Coefficients determined in the previous (Richmond) study are shown on Table V-1.

Table V-1. ABMAC Model: Coefficients from Richmond, California
(Stenstrom et al. 1982)

Land Use	Rainfall/Runoff	Oil and Grease Concentration (mg/l)
Open Land	0.02	0.00
Residential	0.19	3.89
Industrial Property	0.76	7.10
Commercial Property	1.00	13.13
Parking Lots	0.94	12.81
Freeways & Railroads	0.90	7.04
Commercial/Industrial	0.88	10.12
Mean (for use in current study)		

The design of the sampling program, which did not include flow measurements, prevents recalibration of rainfall/runoff coefficients for model verification. Oil and grease concentrations were calculated based on results from the current study and compared to those obtained from work in Richmond. Since separate coefficients were calculated for commercial and industrial property in the Richmond study, and land use throughout the region was determined considering these uses together, mean values of the coefficients were determined for use in this study.

As described in the preceding chapter, data were quite variable. While oil and grease concentrations correlated significantly as a function of land

use, much of the variability was independent of either land use or storm type. Thus, the use of a single coefficient to describe oil and grease concentration characteristic of each land use has considerable inherent error. This error effectively restricts use of the model to provide estimates of long-term loading, rather than to predict loading from individual storms. Since the model is being applied to predict long term differences in loading as influenced by land use, this error is not critical to the analysis. The precision of the analysis, however, reflects the variability inherent in oil and grease concentrations found in surface runoff.

Oil and grease coefficients for each land use were determined by solving a set of simultaneous equations based on the monitoring data. As shown on equation V-1, oil and grease coefficients characteristic of each station can be calculated using information on runoff coefficients and oil and grease concentrations at each station.

$$C = \frac{\sum_{u=1}^3 A_u R_u O_u}{\sum_{u=1}^3 A_u R_u} \quad (V-1)$$

Where: C = Measured Oil and Grease Concentration
 A_u = Land Area Devoted to Use u
 R_u = Rainfall/Runoff Coefficient of Use u
 O_u = Oil and Grease Coefficient of Use u
and u is determined for three land uses:
(1) undeveloped, (2) commercial/industrial and (3) residential

This equation applies equally to each sample taken during the study. Since the majority of the runoff into the Bay occurs during the periods of active rainfall, only those samples taken during the active part of the storm (Type 1) were used in the analysis. Thus, there are 3 unknowns (oil and grease coefficients for commercial/industrial, residential and undeveloped land uses) and thirty four equations (total samples taken during Type 1 storm conditions). No unique solution exists to solve for these 3 unknowns since land use was not the only determinant of oil and grease concentration. The best solution was found using a least squares procedure, which also provides information regarding the variability of the

data around the best estimate of appropriate coefficients.

The least squares procedure uses data equally from all size streams. This approach was taken because the factors affecting oil and grease concentration were assumed to be independent of watershed size, a basic premise of the model. Thus, a large stream draining a watershed with any land use distribution would have the same oil and grease concentration as a small stream draining a watershed with identical land use distribution. Impact on the receiving waters from different sized systems with similar land uses would differ, however, due to larger streams carrying higher mass loads of oil and grease.

Results of performing a regression using these land uses as the independent variables are shown on Table V-2. The coefficient describing the undeveloped land use was negative, and thus meaningless. The coefficient for undeveloped land use was set at 0 mg/l (as previously used for the Richmond study) and the regression performed for only commercial and residential land use. The results of this second regression are shown on Table V-3.

Table V-2. Results of Multiple Regression to Determine
Best Oil and Grease Coefficients by Land Use

<u>Independent Variable</u>	<u>Parameter Estimate</u>	<u>Prob >T</u>
Comm	21.05	0.0017
Undev	-3.28	0.6438
Res	4.15	0.5572

Table V-3. Results of Multiple Regression to Determine
Best Oil and Grease Coefficients by Land Use
(Setting Undeveloped = 0)

<u>Independent Variable</u>	<u>Parameter Estimate</u>	<u>Prob >T</u>
Comm	21.64	0.0009
Res	2.73	0.6632

The oil and grease coefficient of 21.64 mg/l for commercial/industrial land use is considerably greater than found in the Richmond study. This relatively high figure was heavily influenced by relatively few high data points, mainly the concentrations of greater than 40 mg/l found at Temescal Creek in November, with only 4 other measurements greater than 20 mg/l. Rather than ignore these high readings, they were included in the analysis as they indicate the sporadic nature of hydrocarbon introduction. Subsequently, modelling was done using both the coefficients determined through the regression, and using the (much lower) coefficients determined in the Richmond study.

MODELLING RESULTS

The model was run considering average, high and low rainfall conditions. Average rainfall was determined for the stations at Saint Helena, San Francisco WSO AP, San Francisco WSO CI, and San Jose by looking at the monthly departure from normal rainfall in the Climatological Data Annual Summary (NOAA 1983), which considers the period 1951-1980. For the other stations, for which data were not given on departure from normal, precipitation was averaged for the years 1975-1983 for those years with available data. High rainfall was determined by using the rainfall record from calendar year 1982, the year with the highest rainfall in the Bay Area

during the period 1975-1983. Similarly, the year 1976 was used to represent low rainfall conditions, since it had the least amount of precipitation in the Bay Area during the period 1975-1983 (and probably for the last 50 years). On occasion, rainfall data were missing for a given month. An estimate for this missing rainfall data was generated by calculating the ratio of precipitation from the current and following years at a neighboring station and using this as a factor to calculate rainfall for the missing month using data from the following year (Equation V-2).

$$R_x = \frac{r_x(R_{x+1})}{r_{x+1}} \quad (V-2)$$

where: R_x = unreported rainfall station R in month x

R_{x+1} = reported rainfall station R in month x in following year

r_x = reported rainfall station r (neighboring station R) in month x

r_{x+1} = reported rainfall station r in month x in following year

The results of running the model under these three flow conditions, using coefficients from the Richmond study as well as the current study, are shown on Table V-4.

The model was also run considering projected land use in the year 2000 from census data (see Chapter III). Results of this simulation, shown on Table V-5, show that the projected growth in the region will result in substantially greater oil and grease loading. Hydrocarbon loading to the Bay from local sources is projected to increase in the next 15 years from 8 -15 percent with respect to years with similar rainfall.

Table V-4. Total Oil and Grease Loading to San Francisco Bay from Local Runoff Considering Year 1985 Land Use

<u>Rainfall Conditions</u>	<u>Pollutant Load (Thousands of Pounds)</u>	
	<u>Richmond Study</u>	<u>Current Study</u>
Low	2571	4832
Mean	5317	9855
High	8052	15008

Table V-5. Total Oil and Grease Loading to San Francisco Bay from Local Runoff Considering Projected Year 2000 Land Use

<u>Rainfall Conditions</u>	<u>Pollutant Load (Thousands of Pounds)</u>	
	<u>Richmond Study</u>	<u>Current Study</u>
Low	2847	5262
Mean	6108	11148
High	9106	16681

Discharge from commercial/industrial areas is of particular concern, since concentrations are sporadically high and are responsible for considerable

quantities of oil and grease entering the Bay. If these high concentrations were eliminated, total loading would decrease substantially. A scattergram was examined to indicate which measurements appear atypically high (Figure V-1). Coefficients were re-calculated for oil and grease without taken into account the two measurements greater than 40 mg/l (from Temescal Creek in November), which may be an artifact of a single, short lived event. The oil and grease coefficient for commercial/industrial land use was reduced about 25 percent, from 21.64 mg/l (Table V-3) to 16.67 mg/l (Table V-6). Eliminating these high measurements was done to simulate an effective control program minimizing both intentional dumping into the storm sewer and poor housekeeping practices where substantial quantities of oil and grease are leaked or spilled in the watershed.

Table V-6. Best Oil and Grease Coefficients by Land Use after Eliminating Outlying High Values
(Setting Undeveloped = 0)

<u>Independent Variable</u>	<u>Parameter Estimate</u>	<u>Prob >T</u>
Comm	16.67	0.0001
Res	2.11	0.5782

Re-defining oil and grease coefficients based on eliminating the highest oil and grease measurements reduces estimates of total loading into the Bay by about thirty percent (Table V-7, Table V-4). However, it is not appropriate simply to discount sporadically high oil and grease measurements as anomalies, and only consider low readings for calculating loading. These high readings are indicative of real inputs into the Bay. The utility of eliminating high readings from the analysis is to indicate the potential for reducing hydrocarbon loading should these sporadic inputs be controlled.

PLOT OF OIL_T+PRCOMM LEGEND: A = 1 OBS, B = 2 OBS. ETC.

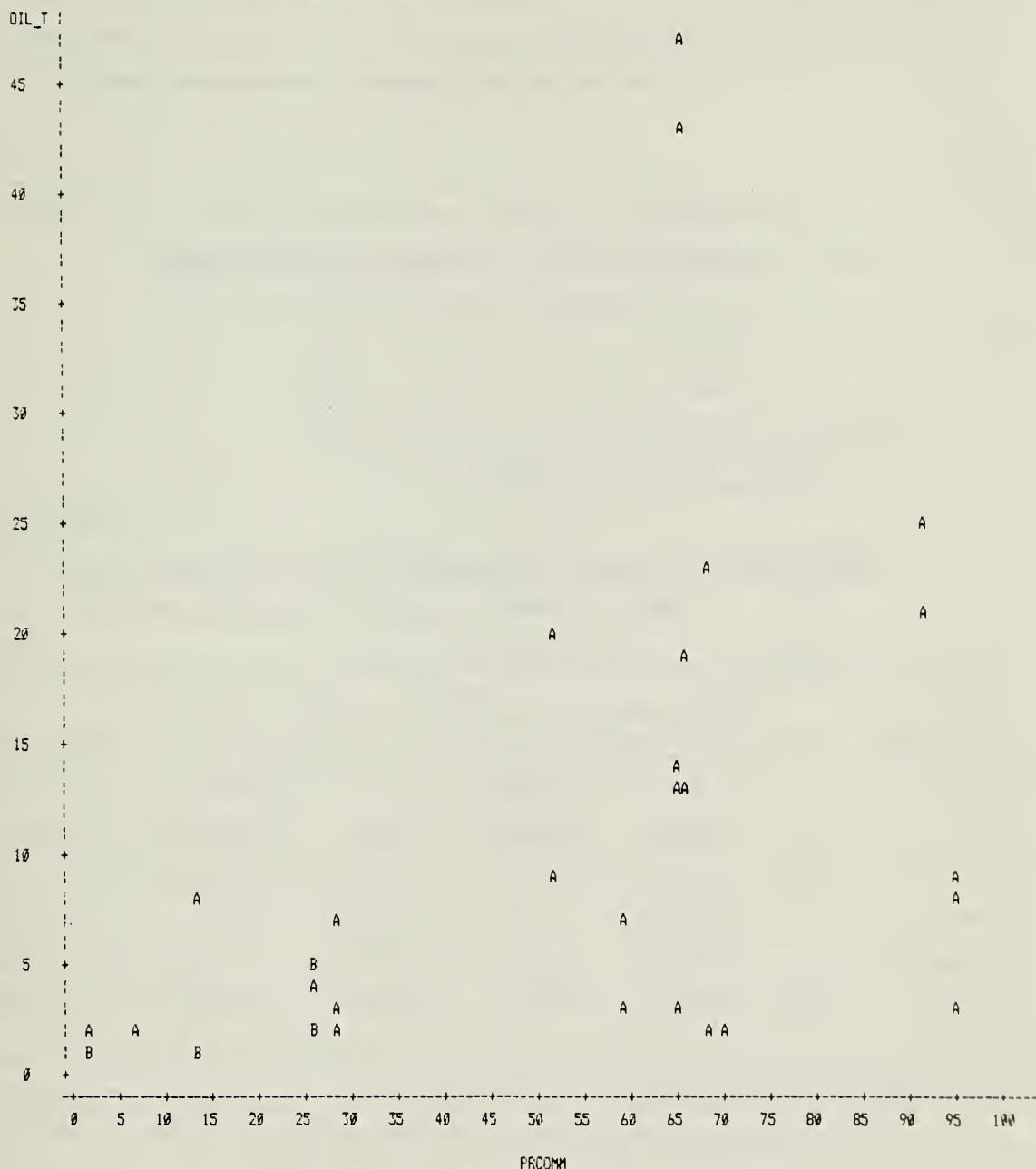


Figure V-1. Scattergram of Total Oil and Grease (0.1-T) in mg/l vs Land Use (Prcomm) in Percent for Storm Phase I

The projected 8 - 13 percent increase in oil and grease loading by the year 2000 results from a relatively small increase in land development (Table V-8). Of the approximately 3 million acres considered as local watersheds to the Bay, approximately 4.0 percent additional land will be developed, of which about 87.5 percent will be residential and 12.5 percent will be commercial/industrial.

Table V-7. Total Oil and Grease Loading to San Francisco Bay from Local Runoff Considering Year 1985 LandUse and Eliminating Outlying High Values

<u>Rainfall Conditions</u>	<u>Pollutant Load</u> (Thousands of Pounds)
Low	3726
Mean	7599
High	11671

Table V-8. Changes in Projected Land Use^a between Years 1985 and 2000 in the San Francisco Bay Area

<u>Land Use</u>	<u>Year</u>				<u>Percent Change</u>	
	<u>1985</u>		<u>2000</u>			
	<u>Acres</u>	<u>Percent of Total</u>	<u>Acres</u>	<u>Percent of Total</u>		
Resid	287757	9.5	362391	12.0	3.5	
Comm	109085	3.6	123371	4.1	0.5	
Undev	2632635	86.9	2543707	84.0	-2.9	

a = rounding errors responsible for deviation from 100 percent and difference in total acreage between 1985 and 2000.

Most of this projected increase in loading is due to the projected increase in commercial/industrial land area. Neglecting the projected increase in residential area, and assuming that all new commercial/industrial development comes from previously undeveloped land, account for over 98 percent of the projected change in loading by the year 2000 (Table V-9). Thus, it appears that the contribution of both residential and undeveloped land uses to total Bay oil and grease loading are generally insignificant, although localized inputs at specific discharge points may be important.

Table V-9. Total Oil and Grease Loading to San Francisco Bay from Local Runoff Comparing Projected Growth with Exclusive Growth of Commercial Area

<u>Simulation^a</u>	<u>Pollutant Load (Thousands of Pounds)</u>	
	<u>Richmond Study</u>	<u>Current Study</u>
1985	5317	9855
2000	6108	11148
Increment due to commercial/industrial increase	686	1223
Increment due to residential change	105	70

^a = mean rainfall conditions

While it is clear that substantial quantities of oil and grease will enter the Bay from local runoff, it is important to put this input into

perspective with other sources. The other main sources of oil and grease into San Francisco Bay are local point sources. While no comprehensive work has been published detailing input from point sources, two studies have examined this issue in part. Citizens for a Better Environment (CBE 1983) reported on oil and grease in effluent from major publicly owned treatment works (POTWs) and major industrial dischargers. Major findings were that about 11.5 million pounds of oil and grease were discharged annually from local point sources into the Bay, with about 90 percent of that input from POTWs.

Russell et al. (1984) estimated inputs of flow, heavy metals, suspended solids, BOD, total nitrogen and total phosphorus from Bay Area point sources. Using their flow data, estimates of oil and grease loading were generated by assuming levels of oil and grease in typical discharge. Using 10 mg/l as a conservative approximation of oil and grease concentration, total loading into the Bay would be about 14 million pounds, with a projected increase to 19 million pounds annually by the year 2000.

These estimates of loading suggest that while nonpoint sources will contribute significantly to total Bay loading, point sources will continue to be responsible for the majority of total input Table V-10. The nature of the input will vary considerable between these two sources, since point sources tend to discharge at a relatively consistent flow rate and concentration while non-point source discharge occurs over a very limited period with great variation in pollutant concentration.

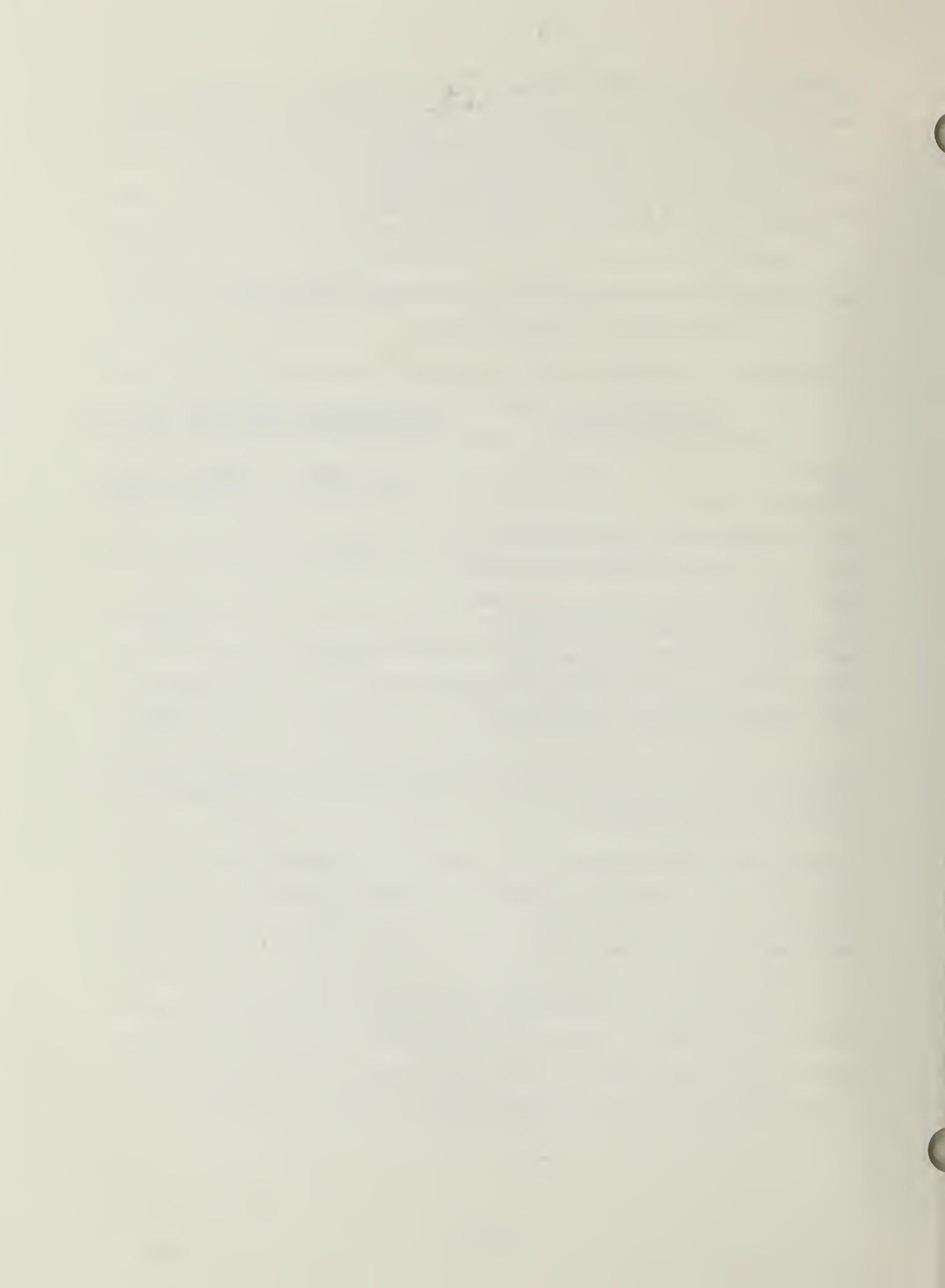
Obviously key to controlling oil and grease loading from Bay Area runoff is the control of input from commercial/industrial land uses. Examination of Figure V-1 suggests that a relatively low baseline concentration of oil and grease is always present in each station. More heavily developed watersheds frequently, but not always, have hydrocarbon levels in runoff greatly exceeding this background level. This suggests that relatively high concentrations are due to a relatively few events - and that if an event does not happen the concentration may be low even in a highly developed watershed. The likelihood of an event occurring appears to increase as a function of

development in the watershed. These events may include intentional dumping, an inadvertant spill, or a major source of leakage. Regardless of the cause, it is clear from the results of the modelling that control efforts concentrating on the commercial/industrial sector show the most promise for limiting hydrocarbon input to the Bay.

Table V-10. Estimates of Point Source and Nonpoint Source Loading of Hydrocarbons to San Francisco Bay

<u>Year</u>	<u>Basis of Estimate</u>	<u>Annual Loading (Thousands of Pounds)</u>	
		<u>Point Source</u>	<u>Nonpoint Source^a</u>
1978	Russell et al. extrapolation	14,000	
1982	Citizens for a Better Environment	11,500	
1985	ABMAC -Current study coefficients		9,855
1985	ABMAC - Richmond coefficients		5,317
2000	Russell et al. extrapolation	19,000	
2000	ABMAC - Current study coefficients ^a		11,148
2000	ABMAC - Richmond coefficients ^a		6,108

a = mean rainfall conditions



CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

This project had several objectives. An analytical technique was developed to investigate methods for obtaining more information about the origins and toxicity of extractable organics in runoff than can be obtained from oil and grease tests, while remaining suitable for routine application. Runoff from around the San Francisco Bay Area was sampled to determine differences in extractable organic constituents as a function of land use, and to model total input into San Francisco Bay. These results, coupled with the results of an earlier phase of study where environmental effects and potential mitigation measures were explored (Stenstrom et al. 1982, 1984), were then used to develop recommendations for implementation of Best Management Practices.

ANALYTICAL TECHNIQUE

Techniques available to analyze for extractable organics in freshwater were reviewed. A procedure was selected for use which showed particular promise based on its ability to separate distinct fractions, its increased sensitivity over standard oil and grease tests, and its relative simplicity. Gas chromatography was used as a means of exploring the chemical characteristics of each fraction and to evaluate the utility of the separation procedure.

The selected technique was shown to have excellent recovery of non-polar organics, losing some effectiveness with the more polar fractions. Separation between fractions was well over 90 percent

The automated shaker/stirrer system improved extraction precision by allowing the use of large samples. The large sample volume increased the quantity of extracted organics, which improved gravimetric precision and accuracy. Precision also was increased through the use of a 25 ml weighing

flask in place of a 125 ml weighing flask recommended in Standard Methods. Increased gravimetric precision eliminated the need to use an infrared spectrophotometric method. It was desirable to avoid the use of an IR spectrophotometer because of sample losses associated with filling and emptying the IR cells, difficulties of calibration when specific compounds are unknown, and the need to develop a method requiring a minimum of expensive equipment.

Thus, the analytical technique provided the needed capability to assess specific fractions extracted in traditional oil and grease procedures. The utility of this technique was then explored through application on runoff samples collected from a variety of land uses throughout the San Francisco Bay Area.

SAMPLING RESULTS

Applying this technique to samples from a number of different watersheds revealed that the chemical make-up of the extractable organic fractions was fairly similar in all watersheds. Anthropogenic sources were responsible for most of the inputs, even in watersheds that were largely undeveloped. Automotive oil and diesel fuel were usually the predominant sources of aliphatic hydrocarbons. Plant/microbial waxes were also regularly observed, and found to be in proportionately greater quantity in undeveloped watersheds than in developed watersheds.

Land use was significantly related to oil and grease concentration, but could account for relatively little of the measured variability. Undeveloped watersheds regularly had low oil and grease concentrations in runoff, while the more developed watersheds had a much larger range of concentrations. Only part of this variation was attributable to differences in storm phase. Aliphatic hydrocarbons comprised a greater percentage of the total hydrocarbon fraction in runoff from developed watershed than in runoff from undeveloped watersheds.

A difference in the nature of the organic material in a watershed was found by examining the relationship between total organic carbon and

oil and grease from watersheds with different land uses. The ratio of TOC to oil and grease was found to decrease with urbanization, suggesting that this ratio could be used as an indicator of watershed development. The relationship between this ratio and land use appears to be due to a difference in the material sampled by each test. Total oil and grease measurements include humic substances from biogenic sources and organics extractable with freon. Oil and grease measurements include only material extractable with freon; the biogenic humic fraction is not included. Thus, runoff from developed watershed should have relatively more oil and grease and relatively less humic substances than runoff from undeveloped watersheds.

The low oil and grease concentrations found occasionally in runoff from the more heavily developed watersheds may indicate that a relatively low background level was typical of all developed watersheds. The sporadic, high concentrations may be indicative of discrete events adding considerable quantities of materials to the watershed. These events could be relatively large spills or leaks, or discharge from facilities. Alternatively, this large variation in concentration could indicate "slugs" of material entering the storm drain from areas such as parking lots where numerous small sources contributed to total loading. However, if concentration simply reflected travel time from areas of high concentration, the variability at the mouth of the watershed would have been moderated through the effects of numerous inputs entering the stream at varying times. This suggests that the variation may have been influenced more heavily by a few discrete sources rather than many small sources. While this conclusion is very preliminary, and requires additional research, the distinction is important when considering implementation of effective Best Management Practices.

Oil and grease concentrations did not vary in a regular manner with other, more easily measured water quality parameters. Thus, no indicator parameters were identified as potential substitutes for routine monitoring of oil and grease.

Gas chromatography was used to investigate the nature of specific hydrocarbons fraction. While the purpose for its use was not routine

application, features were revealed which suggest the utility of GC as an investigative tool for identification of sources of extractable organics loading in the watershed. Predominant sources of aliphatic hydrocarbons were automotive oils and diesel fuels. A relatively large source of diesel fuel in the Temescal Creek watershed was easily located within a few square block radius through examination of gas chromatographs. Input of aliphatic hydrocarbons not usually found in quantity in runoff was readily apparent, where only two unidentified patterns were not easily identified in examination of 69 chromatographs.

MODELLING RESULTS

The ABMAC model was used to predict oil and grease loading into San Francisco Bay from local runoff. Calculations were run using a variety of assumptions, indicating the sensitivity of the model. United States census data were used as the original source of land use data, with predictions of future land use conditions based on projections by the Association of Bay Area Governments (1984).

Calibration of the model using data from the current study resulted in estimates of total oil and grease loading more than 85 percent higher than estimates based on the previous study in Richmond (Stenstrom et al. 1982, 1984). The higher estimates were based in large part to just a few high oil and greases measurements. However, discounting these high readings as anomalies fails to consider the sporadic nature of oil and grease loading to a watershed. Therefore, simulations were run reflecting conditions as found in Richmond and conditions found in the current study, providing an indication of the sensitivity of the analysis.

Between 5.3 and 9.9 million pounds of oil and grease were predicted to enter San Francisco Bay in a year with average rainfall from local runoff sources. Loading was predicted to increase in the next 15 years from 8 to 15 percent. During years of much heavier rainfall, oil and grease in runoff was predicted to increase dramatically, with between 8.0 and 15.0 million tons entering the Bay from local runoff sources. Only between 2.6

and 4.8 million tons were predicted to enter the Bay during years with very little precipitation.

The influence of various land uses was investigated on oil and grease loading. The development of only 14,300 acres of land for commercial and industrial use, representing about 0.5 percent of the total area in the local Bay drainage, was shown to account for almost all of the 8-15 percent predicted increase in oil and grease loading.

The significance of hydrocarbon loading from runoff to the Bay was examined with respect to point source discharges. Extrapolating from the work of Russell et al. (1984) and Citizens for a Better Environment (CBE 1984), estimates were made of point source oil and grease loading to San Francisco Bay. The total volume of oil and grease from nonpoint sources entering the Bay appears to be somewhat less than from point sources. Future work is needed to quantify point source loading to make a better comparison of sources; preliminary indicators are that non-point sources are responsible for between 38 and 86 percent of the loading from point sources. Additionally, the nature of the input will vary between the two sources. Point sources tend to discharge at a relatively consistent rate in terms of both pollution concentration and flow, while non-point source discharge occurs over a limited period with great variations in pollutant concentrations.

The review conducted in the previous phase of this work (Stenstrom et al. 1982, 1984) indicated that there are significant environmental effects associated with oil and grease pollution, and that continuous low level pollution can change the ecology of a marine environment. The results of this modelling effort reveals that substantial quantities of oil and grease enter the Bay from local runoff sources. Particularly vulnerable sites are near outfalls from highly developed watersheds. Future work determining specific cause/effect relationships between Bay biota and extractable organics in runoff would best be determined near these outfalls.

BEST MANAGEMENT PRACTICES

The results of the project clearly indicates that the best opportunity for controlling oil and grease inputs from the local drainage into San Francisco Bay is to limit the input from commercial and industrial areas. Since it is not reasonable to consider limiting growth of the industrial/commercial sector to control oil and grease inputs, mitigation measures can be best focussed on methods to lessen the contribution from these sources.

Best Management Practices for controlling oil and grease were developed in the previous phase of this work, examining a single watershed in Richmond. Based on current data, these practices were reviewed to determine which have the greatest potential for limiting the input of oil and grease into San Francisco Bay from local runoff sources. Reprinted below are descriptions of those Best Management Practices previously recommended as having the greatest potential for limiting oil and grease input into the Bay (Stenstrom et al. 1982, 1984). Following these descriptions are recommendations for implementation.

Favorable Non-Structural Control Techniques

Non-structural control measures comprise techniques utilizing existing technology and physical facilities to reduce the detrimental effects of oil and grease released into the environment. These measures can include mechanisms for limiting oil and grease discharge at its sources, cleaning oil and grease deposits prior to incorporation into stormwater and modifying areas of deposition to minimize harm. Non-structural control measures often can be implemented quickly, without the long lead-time usually required for construction of structural control equipment. Non-structural control measures often take the form of economic incentives or penalties, government regulations, persuasion, and direct intervention. The major difficulties inherent in selecting appropriate non-structural control measures are determining the effectiveness and associated costs of any proposed measure, and determining how to select measures that are equitable among the affected parties.

Oil and Grease Recycling An attractive mechanism for reducing automotive oil input into a watershed is to encourage the recycling of used crankcase oil, in lieu of dumping. The National Recycling Coalition (1981) reports that 1.2 billion gallons of lubrication oil are used annually in the United States. Approximately 35% of this lubricating oil is lost or consumed due to leaks and combustion, resulting in over 750 million gallons of used automotive oil potentially available for recycling. Another 0.65 billion gallons annually of waste oil is potentially available from industrial sources. Since the re-refining capacity of the United States is only about 150 million gallons of oil per year (National Recycling Coalition, 1981), it is apparent that greater capacity is needed to recycle the bulk of the waste material. The large difference between waste oil quantities and recycling capacity indicates that there is a significant quantity of waste oil which probably enters the environment through stormwater and other discharges.

In California, the Used Oil Recycling Act of 1977 (S8 68) was adopted in recognition of the potential for waste oil recovery. Moskat (1980) of the California Solid Waste Management Board estimates that in 1980 over 96 million gallons of used oil were available for recovery in the state, consisting of about 58 million gallons of used automotive type and 38 million gallons of used industrial oil. Approximately 36 million gallons of oil were re-cycled in California during 1980, a much greater reuse percentage than for the nation as a whole. However, there remains a large quantity of waste oil that is probably being illegally dumped.

The economic incentive to the individual motorist for waste oil recycling is low, even though value of waste oil has dramatically increased over the past decade. To illustrate the lack of incentive, it is helpful to consider a simple example. Most automobiles use four to six quarts of crankcase oil, and even if the oil were worth \$0.80/gallon (the approximate value of crude oil), the financial incentive for individuals to recycle is only about \$0.80 to \$1.20 per oil change. This lack of economic incentive for oil recycling and other aspects of oil recycling are further discussed by Weinberger (1974), who concludes that institutional methods need to be developed before a high percentage of individuals will recycle used oil.

Novel institutional incentives may be needed, such as the construction of recycling centers, which provide facilities for the individual motorist to change crankcase oil. The convenience of using the facility (crawling under one's automobile to reach an oil pan is an unpleasant task to most motorists) may significantly increase recycling. The cost of the center could be partially recovered by the value of the reclaimed oil, or through franchises to oil venders who could be given space at the center.

The data collected in this study do not identify the route of oil introduction into the Richmond watershed; it is insufficient to accurately separate the contribution of oil and grease in the runoff resulting from illegal dumping from the contribution resulting from legal vehicle operation.

However from the National Recycling Coalition's (1981) estimate for current recycling, and their estimates that 35% of automotive lubricating oil is lost to leaks and combustion, it appears that 60 million gallons of waste oil is unaccounted for, with an unknown portion being illegally dumped.

Vehicle Inspection and Maintenance Programs. These programs may also prove effective in reducing watershed oil and grease loading resulting from automotive combustion emissions and crankcase drippings. Recognizing that 35% of crankcase oil may be released to the watershed during normal vehicle operations, a significant decrease in watershed oil and grease will probably result from improved vehicle performance and maintenance. The potential decrease can be projected from Moskat's estimate of 140 million gallons of new oil sold in California in 1980. Therefore, approximately 35% or 49 million gallons of crankcase oil are lost annually through motor vehicle operation.

The data from this study conclusively indicates that locations with the highest motor vehicle activity produce the highest oil and grease mass emission. This supports the hypothesis that improved motor vehicle condition

will be an effective mechanism to reduce oil and grease emissions. It has been shown that the existing California inspection program required in the sale of a motor vehicle results in a mean reduction in hydrocarbon emissions of 11% (Department of Consumer Affairs and California Air Resource Board, 1981). A proposed, improved inspection procedure is projected to result in a 15 to 20% reduction in hydrocarbon emissions. This reduction further supports the value of vehicle inspection programs to reduce oil and grease emissions in urban stormwater.

Establishing a program to improve the condition of motor vehicles is potentially difficult and expensive. However, a vehicle inspection program may become practical if associated with vehicle inspection for air quality control. Section 172 of the Federal Clean Air Act mandated that individual states, in areas of non-attainment of air quality objectives, "establish a specific schedule for implementation of a vehicle emission control inspection program, it may be possible to expand the objectives to include some regulations concerning oil emissions and leakage.

Satisfying automobile air quality objectives through an inspection and maintenance program would result directly in a decrease in oil associated with particulate emissions deposition. Limiting oil leakage through a vehicle inspection and maintenance program appears more difficult. There are many potential sites for oil leakage in an automobile engine, many of which are quite expensive to repair. Any program requiring the mandatory repair of all oil leaks would probably be impractical. However, an inspection program locating some areas of oil leakage may provide incentive for some individuals to repair their automobiles.

The data from this study do not separate the relative contributions to the watershed of oil and grease exhaust deposits from oil and grease drippings. However, since vehicle activity is associated with areas of high oil and grease levels in stormwater runoff, an inspection and maintenance program of even limited effectiveness and may prove beneficial in significantly reducing total watershed oil and grease loading.

Identification of Critical Components of Oil and Grease - In Chapter 3 of this report reviewing the effects of oil and grease on the environment, it was recognized that toxicity varies substantially with the type of hydrocarbon constituents of the oil and grease. Currently, the only control of petroleum hydrocarbon discharge is through oil and grease NPDES permits and other regulations on point source dischargers. In many instances the NPDES permits

or other regulations do not specifically control the toxic constituents in oil and grease, but only regulate the maximum concentration or total mass discharged. Therefore specific hydrocarbons in concentrations which might be toxic or harmful can be legally discharged from industries and municipal waste treatment facilities. Furthermore, the concentration of oil and grease in the stormwater runoff in the Richmond watershed was sufficiently high to potentially cause environmental harm to the Bay if the monitored oil and grease contained significant fractions of specific toxic hydrocarbons.

Some additional legislative control of oil and grease appears warranted, specifically with regard to toxic hydrocarbon components. The Regional Water Quality Control Board, which establishes discharge limits based on provisions of the Federal Clean Water Act, appears the most appropriate agency to provide the needed control measures. Furthermore, the hydrocarbon loading from stormwater runoff needs to be examined further to determine the need for adopting non-point source control to further limit hydrocarbon loading into San Francisco Bay.

The costs of imposing additional legislative control are hard to ascertain. The technological requirements to determine levels of specific hydrocarbons or hydrocarbon groups are expensive, requiring sophisticated equipment and substantial expertise. Estimates of costs for effluent clean-up cannot be made without first identifying and quantifying the current hydrocarbon constituents of stormwaters. However, the potential for environmental harm to the Bay from hydrocarbon pollution, and indications of existing harm from current pollution levels, appear sufficiently grave to warrant further investigation and possible regulatory control.

Favorable Structural Control Techniques

The structural control measures considered for recommendation comprise techniques requiring additional equipment and/or materials, or use existing resources in a new manner requiring capital investment to reduce the effects of oil and grease loading in the watershed. Structural measures to control oil and grease usually are employed after the material is deposited within the watershed, rather than reducing the input into the watershed. Due to the expense of most structural control measures, rigorous value assessments need to be made before a measure can be adopted.

The rigorous value assessment needed prior to construction is beyond the scope of this investigation because many of the proposed techniques are new and unproven. Furthermore, detailed cost estimates cannot be made without the services of an Engineering/Architectural firm to evaluate each site.

Cleaning of Surface Material - Land use areas characterized by substantial vehicle densities had the highest concentration of oil and grease in the surface water runoff. On a unit area basis, runoff from parking lots and commercial streets constituted the largest contributors of oil and grease to the watershed. The modeling results indicate that a 90% reduction in oil and grease from commercial streets and parking lots, consisting of only 11.8% of the total land area, would result in over 50% reduction in total oil and grease loading to the watershed. Thus, it appears economical to selectively reduce oil and grease from parking lots and commercial streets in recognition of the advantages of controlling a relatively small area to affect the largest proportion of pollutant control.

Sweeping is the usual method to reduce pollutants from streets and parking lots. Field et al (1977) report that the costs of removing particulates by street sweeping are less than 50% of the removal costs at wastewater treatment plants. However, conventional sweeping practices are of unknown efficiency in reducing oil and grease pollution. Determinations of the proportion of hydrocarbons found on particulates are consistently over 80% (Shaheen, 1975, Hunter et al, 1979, and Eganhouse and Kaplan, 1981) with most pollutants associated with very fine particulates (Sartor et al, 1974). However, Sartor et al (1974) also report that traditional sweepers leave behind most of this fine material (85% of material finer than 43 um and 52% of material finer than 246 um.). Thus, the particles most likely to be left behind by traditional sweeping techniques are those containing the most significant quantities of oil and grease.

A practical method of oil and grease control may result from the utilization of sophisticated cleaning techniques to remove fine particulates. Advanced cleaning methods would probably also improve aesthetics and reduce other contaminant loading to the watershed. The use of efficient cleaning techniques appear to offer a cost-efficient approach to remove oil and grease pollution prior to incorporation into stormwater runoff.

A difficulty inherent in a program to effectively clean areas of high vehicle activity is the lack of information concerning techniques capable of effective sweeping and their associated expense. Considerable modification of existing equipment may be required, which would probably result in initial high costs. However, if standard systems were designed and employed over large areas, economies of scale may result in a cost-effective approach to pollutant limitation.

A method of street cleaning which appears promising is wet-sweeping technique, using specially designed street sweepers. The street sweeper would

first spray a small area with water containing biodegradable soaps or detergents, which serve to solubilize the oil and grease deposited on pavement surfaces. The sweeper next removes the water with a combination of sweeping and vacuum action. A sophisticated version of sweeping truck could contain a filtration system which would treat the recovered water to reduce the volume of oil and grease solution. This proposed sweeping machine is a hybrid of existing technologies and has never before been tested. A series of prototype machines should be developed and evaluated prior to any widespread adoption. As the effects of wet-sweeping on pavements longevity should be evaluated.

Porous Pavement - Another practical method of controlling oil and grease in runoff may consist of modifying pavement material in parking areas. Road surface characteristics have been reported to significantly influence the degree of contaminant loading at a given location (Sartor et al., 1974 and Russell and Blois, 1980). Furthermore, the results of the modeling activity suggest that controlling oil and grease from parking areas would institute an effective mechanism for regulating the total area oil and grease pollution. Although parking lots constitute only 6% of the land area in the study watershed, a 90% reduction in the oil and grease content of stormwater emitted from parking lots would result in about a 25% reduction in the total oil and grease load to the entire watershed stormwater.

The use of porous asphalt pavement may provide a practical means of modifying surface pavement parking material to provide a reduction in pollutant loading. Porous pavements provide a high rate of rainfall infiltration by omitting fine particles during pavement construction. Water is retained in the base and pavement materials, providing an opportunity for pollutant adsorption and degradation. Porous pavement also reduce the magnitude of total peak runoff, providing flood control benefits.

The major difficulty in evaluating the anticipated performance of porous pavements is the lack of data base from which to determine effectiveness and applicability to various situations. Little is known about the maximum safe rate of pollutant loading into porous pavement, before a result in a breakdown of assimilatory capacity occurs. While the initial costs of porous pavements are estimated to be about 50% greater than for conventional pavement (Dinitz, 1980), much of this expense may be attributed to unfamiliarity with construction requirements; porous pavement construction materials and techniques do not appear inherently more expensive than conventional methods. The anticipated reduction in the need for runoff control devices such as sewers, catchment basins and gutters may provide offsetting economic benefits.

Another important unknown quality of porous pavement is its durability. Without an existing long-term record, it is difficult to assess how long this pavement material can be used without restoration, a vital economic consideration. Also the characteristics of oil and grease on porous payment are unknown; the oil may "plug" the pavement, reducing its porosity.

Other types of porous pavement besides porous asphalt may also be practical as parking area surface material, including concrete block type materials allowing vegetative growth directly in the parking area and gravel infiltration areas. These systems offer many of the same advantages and disadvantages of asphalt porous pavement, and suffer the same lack of proven history as effective pavement material. Research is progressing using these materials, with preliminary results indicating that they will at minimum be effective for selected applications.

Oil Sorption Systems - These systems also appear favorable. Oil sorption systems have been developed using a variety of types of materials in order to clean-up oil spills on open waters. These materials, which include naturally occurring material such as straw, hay, shredded urban solid waste, and synthetic materials such as polymethane foam. The development of these techniques was performed in the early 1970's when oil spills were more prevalent. Lengthy evaluations have been reported by Cochran, et al (1973), Miller et al (1973), and Gamtz and Meloy (1973). These reports all address spills, where very high concentrations of oil are present. This contrasts to urban stormwater, where very low concentrations occur. Therefore an experimental program is needed before widespread use can be anticipated.

The experimental programs required to develop the sorption system should not be costly or lengthy. The previously cited studies show that the sorptive capacity of polymethane foams is very large; consequently the problem of sorbing oil and grease from stormwater will become one of designing an appropriate hydraulic structure to provide intimate contact between foam and stormwater, without causing flooding. The previous figures of hypothetical systems (Chapter 4) appear to be acceptable, and contains sufficient mass of sorbent to sorb very large quantities of oil and grease. The hydraulics of the proposed system have not thoroughly been investigated, and will need experimental verification.

The cost of the proposed system will be quite small. It is probable that structural modification of existing sewer will not be required. Maintenance will be required routinely, but will be simple and composed primarily of replacing sorbent and cleaning debris from the sorption system. Sorbent costs

vary widely and prices have been found ranging from \$2.00 to 10.00 per cubic foot.

Greenbelts - One innovative mitigation measure that is uniquely suited to small areas where the stormwater runoff has a high hydrocarbon concentration, such as parking lots, is the construction of greenbelts. The purpose of these grassy areas is to catch runoff from a large paved area and allow it to percolate through soil, thus filtering and adsorbing hydrocarbons, allowing them to be metabolized by naturally occurring soil bacteria. The use of greenbelts for oil and grease control is a new concept; consequently the design must be based largely upon analogies to land and overland treatment.

Most of the literature on treatment of water by land application concerns wastewater treatment (Reynolds et al, 1980). The greenbelt combines aspects of several of the standard application methods (Rich, 1980). The diagram in Figure 7-1 shows a hypothetical application to a parking lot. The lot is graded so that all runoff waters are channeled into one or more greenbelts. At the entrance to the belt is a concrete spreading apron to facilitate equal distribution of the waters over the belt, and lessen the chances of erosion. The greenbelt may consist of a layer of topsoil supporting plant life, underlain by a layer of sand, which rests on a thick bed of gravel. Runoff waters percolate down through the top layers which decrease hydrocarbon concentration through adsorption and filtration. According to Rich (1980), such percolation removes essentially all suspended solids which should also reduce hydrocarbon concentration.

The gravel layer acts both as a drain, keeping the upper layers from saturation, and as a reservoir where stormwater is stored while it percolates into the surrounding soils at depth. Since the soil underlying the parking lot will be isolated from surface infiltration, percolation out of the gravel bed should be quite rapid. For large or very intense storms beyond the design capacity of the greenbelt, a storm drain inlet is constructed on the far side of the belt. In this manner the waters in excess of the greenbelt's treatment capacity are removed, preventing erosion or damage to the plant cover. Note that the greenbelt will absorb the first-flush waters of all storms. It was noted previously that the oil and grease concentration declines with time for the Richmond watershed, and that this phenomena has been noted by others.

The major cost involved in using greenbelts is the land requirement. The price of the land and the proportion of land needed to control runoff will be highly variable, dependent upon local land values, soil conditions and rainfall pattern and quantity. Construction costs should be relatively low for greenbelts in developing areas, requiring mainly gravel, sand, topsoil and

concrete. Building greenbelts in existing parking lots would be more expensive, requiring modification of existing facilities including drainage gradients and storm sewers. Maintenance of the greenbelts also may be a significant cost, requiring trash collection, gardening service, and perhaps dry season watering. However, aesthetic benefits resulting from the greenbelts may help defray many of these costs.

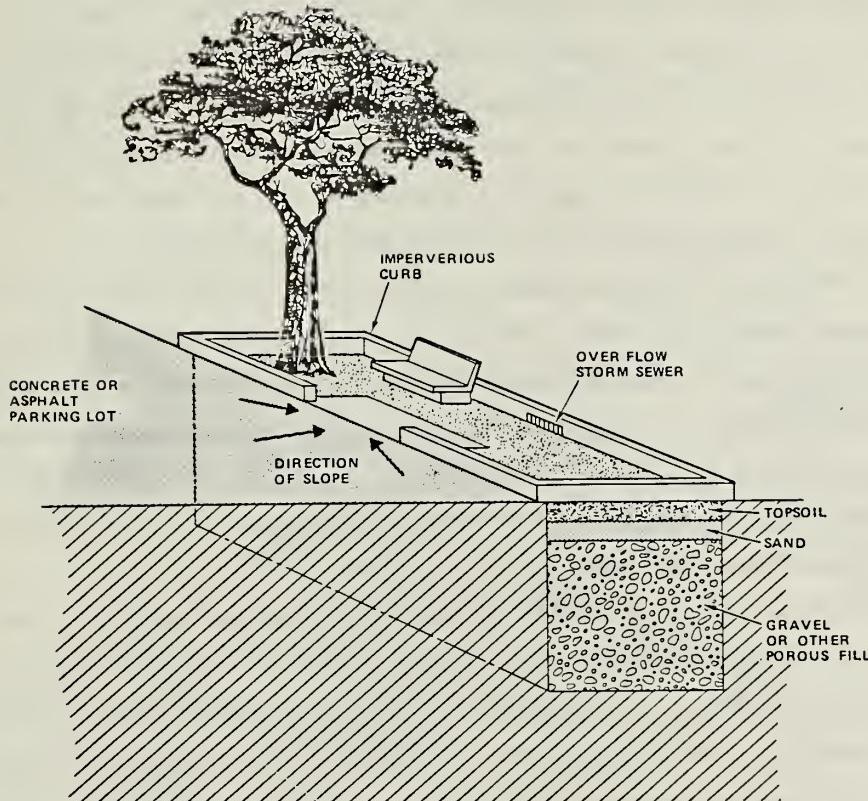


Figure 7-1 Hypothetical Green Belt for Treatment of Stormwaters

Wetlands - Wetlands offer a mechanism for treating stormwater runoff after contamination with oil and grease but prior to its discharge. The general application of this technique is quite limited and site-specific because of the availability of suitable land. However, the Bay Area offers many sites where marshes have been dredged, filled and/or channelled that retain a practical potential for wetland development.

The use of wetlands for stormwater treatment is generally considered a very attractive alternative. Besides meeting water quality objectives,

wetlands offer improved aesthetics, wildlife habitats and recreation areas. However, wetlands also are suspected of being expensive, and little is known about their pollutant removal capabilities.

No information was found describing the effectiveness of wetlands in removing oil and grease from stormwater runoff. Since the majority of oil and grease in runoff is normally found associated with particulates, it would be reasonable to assume that a wetlands would act primarily as a sedimentation trap. Pollutant removal from the water column would occur as the particulates settled, with subsequent degradation responsible for their ultimate elimination. The removal of other pollutants besides oil and grease would also be anticipated. Wetlands have been found to have varying effectiveness in removing certain metals and nutrients from wastewater treatment facility effluents. However, an accurate assessment of oil and grease removal potential cannot be made until pilot studies have been conducted.

The costs of wetlands appear relatively high. Wetlands require a substantial quantity of land. Construction costs for the first wetland areas will undoubtedly be higher than the construction costs of wetlands build after the technology is fully developed. This results because of the increased safety factors needed when designing under uncertainty. However, even the high initial construction costs will be less than the cost of conventional wastewater treatment plants.

Wetlands appear to offer both very attractive and unattractive features. However, the potential value of a wetlands, should it be able to provide substantial water treatment as well as aesthetic, wildlife and recreational values, appears sufficient to warrant further investigation as a favorable control technique.

Dispersion Devices - Diffusers are also a favorable control measure. Dispersion devices have been successfully used for many years to reduce the effects of sanitary and industrial effluents on rivers and oceans. The cities of Los Angeles and San Diego, and the counties of Orange and Los Angeles all use diffusers to mitigate the effects of wastewater treatment plant effluents on coast waters.

A diffuser does not reduce the amount of pollution discharged to the receiving body but dilutes the concentration of the pollutants. For this reason many environmentalists are opposed to diffusers and prefer treatment methods. In the case of urban stormwater, treatment systems are very expensive and are used intermittently, which results in poor performance and reliability. Diffusers however can work well on an intermittent basis and can be fully automated, which reduces operating costs. Furthermore, for small and

medium rains the diffuser may be able to discharge all storm water without pumping. The need for pumping will depend on the tidal cycle and topography.

The major cost of using dispersion devices are the construction costs and operating costs, should pumping be required. To obtain specific cost estimates it would be necessary to select a site, since runoff quantity and pipe length would be highly site specific. However, the capital requirements of a diffuser facility would be expected to be approximately several hundred thousand dollars by cost from an equivalent sized rain water pumping facility (Hansen et al, 1979) and \$25/ft of diffuser pipeline. Additionally, some routine maintenance would be required to keep debris from clogging the system and to keep pumps in good working order. Figures 7-2 and 7-3 show a typical system.

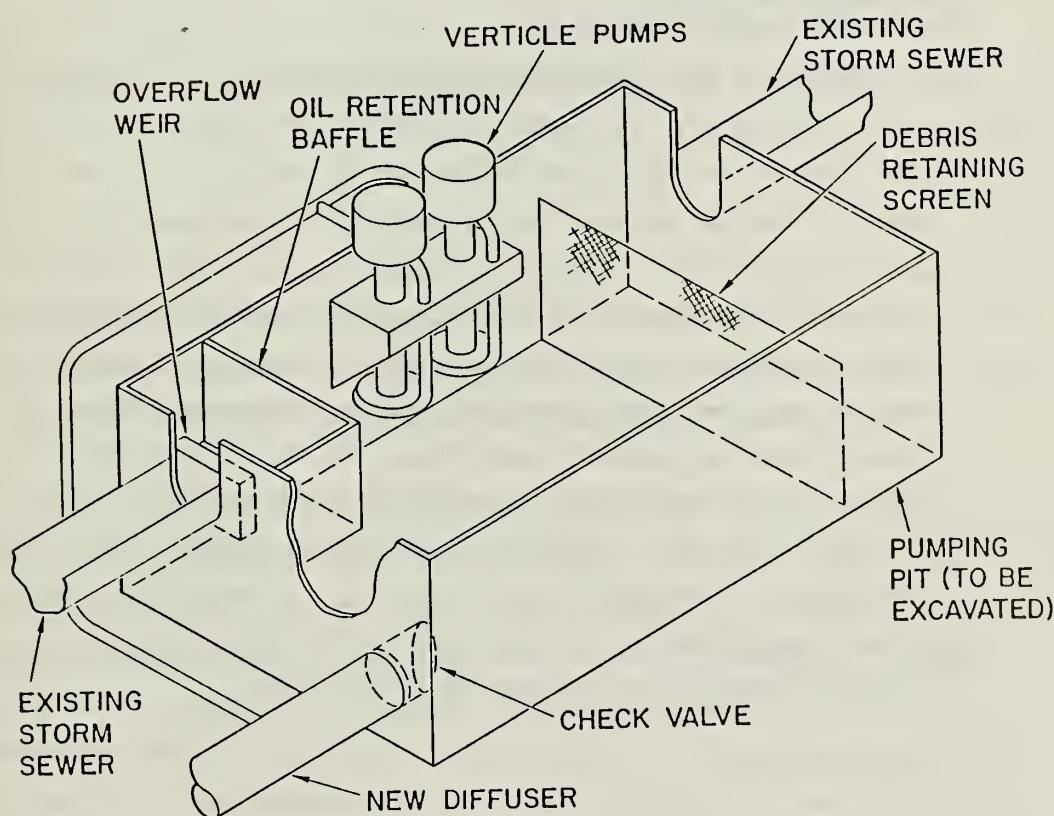


Figure 7-2 Hypothetical Diffuser Pumping Facility Schematic Diagram

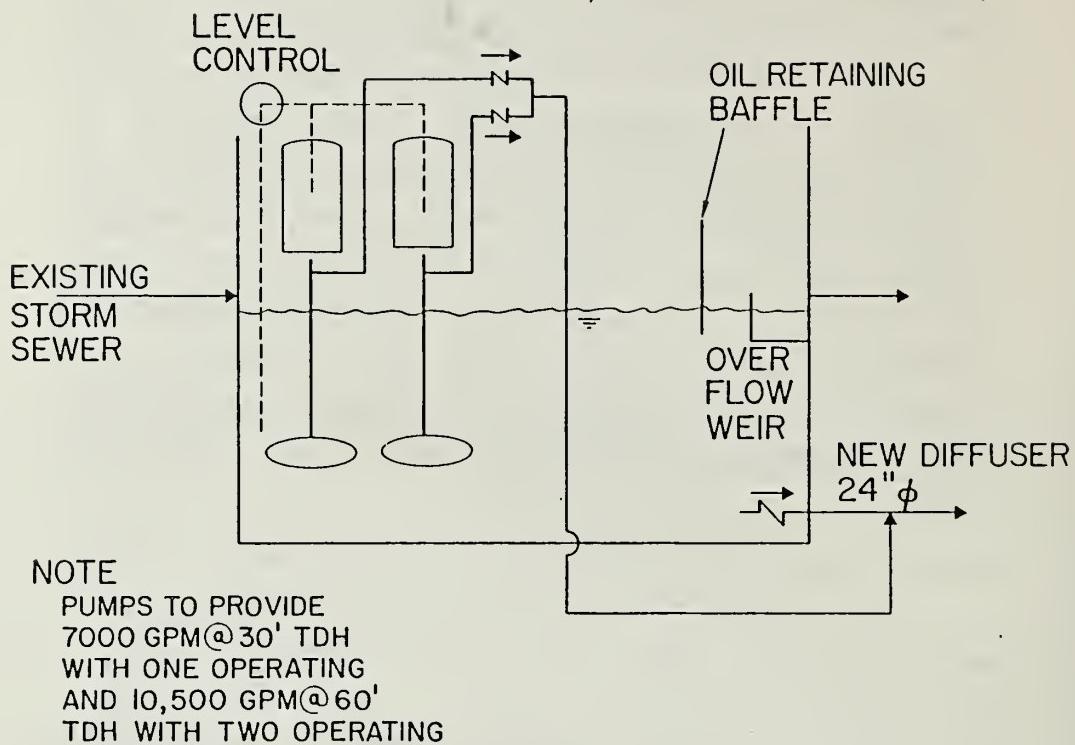


Figure 7-3 Hypothetical Diffuser Pumping Facility Process Flow Diagram

Unknown costs would be those imposed on the environment due to the spreading of pollution. Since the dispersion device is intended to remove pollutants away from critical near-shore areas with subsequent dilution in off-shore areas, environmental costs imposed by the diffuser must be significantly lower than the existing environment damage imposed by runoff to justify the system. The potential for a significant environmental impact from oil and grease has been substantiated in this study, such that diluting runoff pollutant concentrations and removing runoff from sensitive areas appears a favorable mitigation measure, and should be studied further.

RECOMMENDATIONS FOR IMPLEMENTATION

Non-structural Control Techniques

Oil recycling should be strongly promoted as a means of controlling oil introduction into San Francisco Bay. Automotive oil was shown to be a dominant component in oil and grease in runoff regardless of watershed land use. Relatively high concentrations found sporadically from the more developed watersheds could be indicative of dumping as a means of disposal from individuals changing motor oil. People may take more care in disposing of waste oil in residential areas, near their homes, than in industrial areas. While information on individual patterns of waste oil disposal are not available, this concept is supported by the finding of automotive oil commonly present in runoff, with sporadic occurrence in relatively high concentrations from commercial/industrial areas.

Oil may also be introduced into watersheds from automotive leaks. Now in place in California is a vehicle inspection and maintenance program to limit the introduction of air emissions into the environment. A potential exists for expanding this program to look for major oil leaks to limit the introduction of land and water pollutants. While such a program is easily visualized at little additional cost to the vehicle owner through integration with the air emission inspection, adopting such a program would be very difficult given the current regulatory framework.

The California State Air Resources Board (ARB) has implemented a periodic inspection program for automobile exhaust. Control of water pollutants is under the authority of the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCBs). Impetus for adding an oil element to the air program would most likely have to come from and be administered by the Water Boards, necessitating the development of a cooperative agreement with the ARB. State law would have to be passed to mandate such a program, which might be difficult given the lack of Federal directive similar to that for controlling air emissions.

A complicating issue in determining the effectiveness of an oil leakage inspection program is the highly subjective nature of the inspection. In the emissions test there is an established procedure, equipment, and a threshold level for passing or failing vehicles. A check for oil leaks, however, is difficult to standardize.

The pilot inspection/maintenance program run in Riverside, California serves as a good example of the incorporating an oil leakage evaluation within an air emission program. A pre-emissions testing examination was applied to identify vehicles which might constitute a safety hazard in the testing facility. If a vehicle leaked a puddle of oil 3 inches in diameter in one minute, it was rejected. Of the incoming vehicles, 0.01 percent were rejected for oil leaks, 1.2 percent rejected for coolant leaks, and 0.3 percent rejected for fuel leaks (Bureau of Automotive Repair 1976). This pilot program indicates potential for controlling vehicles with major leaks. Controlling minor leaks would require much more sophisticated test procedures. In addition, any program to control minor leaks would have to resolve the problem of even small leaks often being very expensive to fix.

The third non-point source control program recommended in the initial study was to identify critical components of oil and grease in runoff and modify regulations to take into account specific fractions based on toxicity. The results of this study indicate that this is not currently practical for routine monitoring, as hydrocarbon fractions appear similar from different land uses. Additionally, the need for measuring oil and grease can not be reduced by using other water quality parameters as oil and grease indicators.

The identification of specific components or fractions is warranted to locate sources of discharge and identify unusual material in runoff. Examination of gas chromatographs of extracted aliphatics can indicate whether this fraction displays the usual fingerprint, or if unusual material is evident. As shown in this study with the identification of a major input of diesel fuel within a relatively small area, gas chromatography can provide the means to locate specific sources of pollution. If unusual materials are observed in runoff, additional efforts

can be made to identify this material in order to determine its source. Alternatively, additional samples can be taken to pinpoint the origin of unknown material prior to identification, providing information on the probable nature of the material based on the material present at the source.

Thus, oil and grease testing appears best suited for routine examination. Gas chromatography shows potential for use in examining those sites where loading from commercial/industrial areas appears to present the greatest potential for problems, serving as an investigative tool to locate major sources of organic loading to the Bay.

Structural Control Measures

Six structural control measures were previously identified as having the most promise for controlling oil and grease in runoff. Four of these measures, cleaning of surface material, porous pavement, oil sorption and greenbelts, are designed to be used at the point of deposition. The other two recommended measures, wetlands and oil dispersion systems, are designed as "end of pipe" mitigation.

Use of mitigation measures in areas where much of the oil and grease in runoff originates (commercial and industrial areas) is indicated as providing an outstanding opportunity for limiting loading to the Bay. As shown through the use of the ABMAC model, control of relatively small acreage developed as commercial or industrial areas will result in considerable decline in overall loading.

All four of the methods recommended for use at the point of deposition have excellent potential for removal of chronic inputs of oil, typified by inputs such as minor drippage from numerous vehicles in parking lots. However, sweeping may have less potential if much of the input is from a few major incidents, as clean-up may not occur between the time of pollutant introduction and a storm. The other three methods have the advantage of always being available to handle pollutant inflow.

These structural oil and grease mitigation measures are recommended as having the best potential for control, but have never been tested for performance. This type of testing is necessary before widespread application can be considered.

The use of wetlands and dispersion devices can serve to protect vulnerable areas where untreated runoff is currently discharged. Organic pollutants are entering the Bay in considerable quantities from developed watersheds. Future studies should be directed toward looking at cause/effect relationships at areas receiving this discharge. Discharge into sensitive habitats, such as shellfish beds isolated from Bay flushing action, may be responsible for degrading a local habitat without contributing significantly to the total loading of the Bay. Moving the point of discharge to an area of rapid mixing through the use of a dispersion device may provide the simplest means of mitigation. Alternatively, capturing the organic pollutants in a controlled wetland environment prior to discharge can result in protecting the environment at the point of discharge.

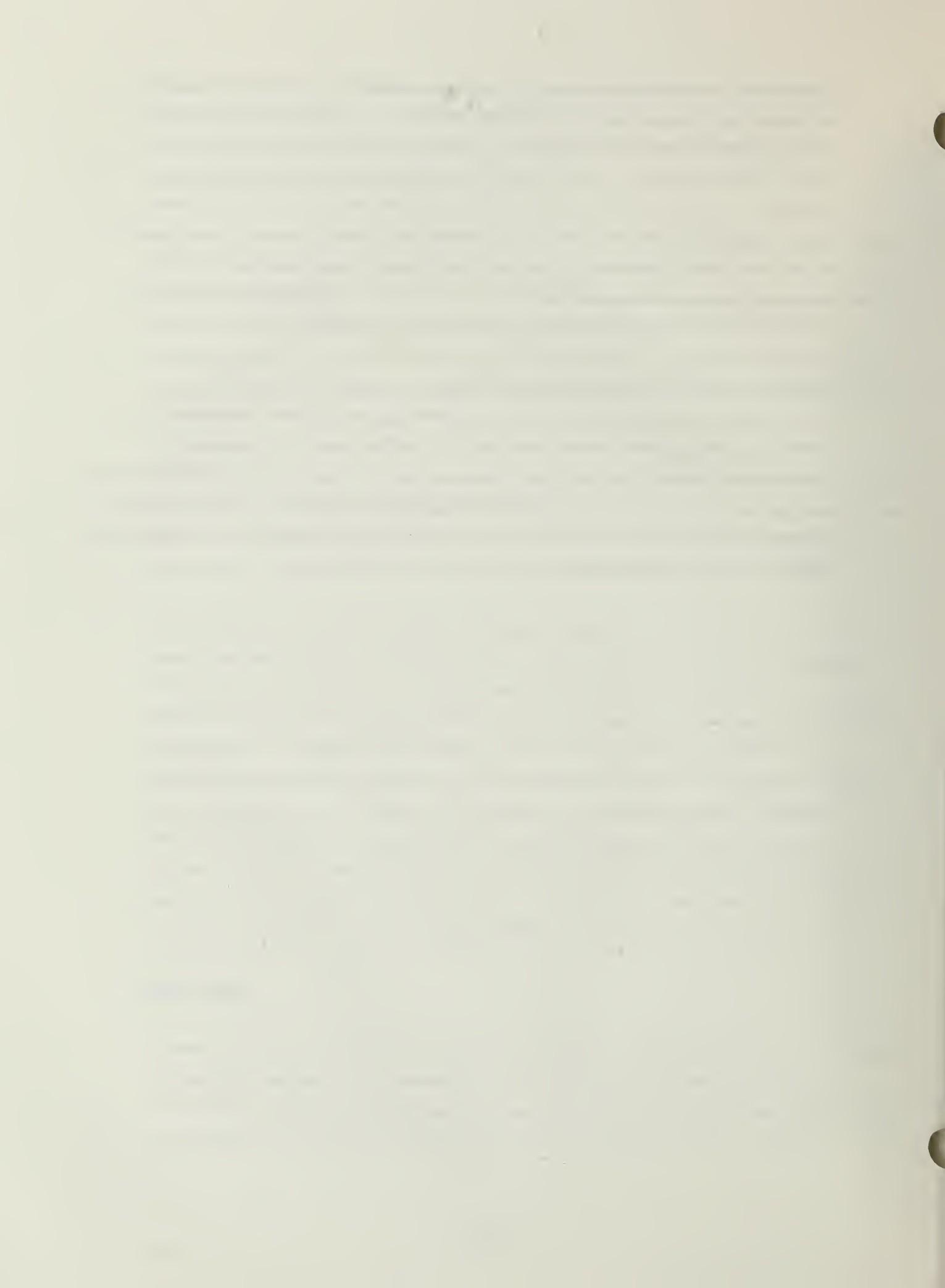
Use of these two "end of pipe" mitigation measures also requires considerable further research before general implementation is proposed. Examination of the biota at locations receiving discharge from commercial/industrial watersheds should be examined to determine the effect of exposure to organic pollutants. The use of wetlands needs to be examined to determine both the effectiveness of pollutant removal, and the environmental fate of these pollutants in a wetland system. Current research by the Association of Bay Area Governments at Coyote Hills Regional Park in Fremont will provide much of this needed information on wetlands receiving stormwater inputs on the Bay. A program needs to be started looking at the localized effects of stormwater discharge.

ENFORCEMENT

A theme running through the discussion of Best Management Practices is that extractable organics are entering the runoff from discharges into the watershed. Such discharges are not permitted, and the RWQCB and SWRCB have the authority to control sources of pollution into the Bay. However, the

nature of non-point source pollution has generally made control very difficult. Tools have been identified in this project which can help in identifying sources of pollution. However, it is still unclear if additional enforcement activities will be directed toward control of these pollution sources. While the Federal government has indicated that a program will be implemented to determine the significance of a stormwater discharge to pollution of the receiving water, the specifics of this program have not been identified. In any case, significant sources of pollution are entering the Bay, and control is needed.

Implementation of Best Management Practices reduces the need for enforcement if they are effective in removing pollutants released in the watershed before they enter the Bay. A combination of increased enforcement activities and Best Management Practices appears to be the best way to protect the Bay from pollutants in local runoff. As demonstrated through the use of the ABMAC simulation model, the problem will continue to grow if action is not taken.



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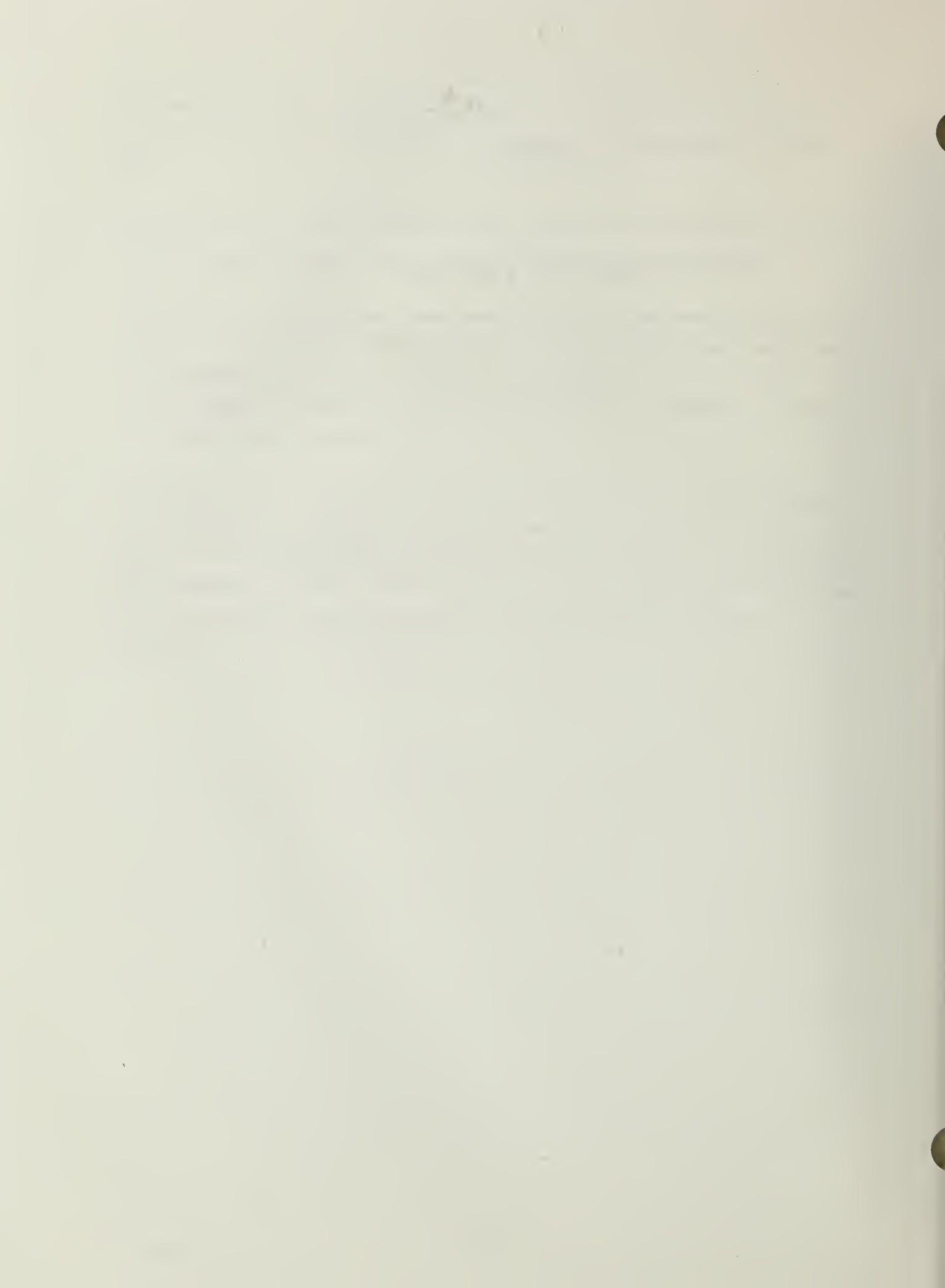
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APPENDIX A

LISTING OF ALL RUNOFF DATA

(See Table IV-1 for abbreviation key)



1SAS

15:43 FRIDAY, SEPTEMBER 27, 1985 1

OBS STATION	FESIO	COMM UNDEV	ROADS AREA	FRCOMM	DATE	TYPE	OIL_SOL	OIL_PART	OIL_T	FALIP	FAROM	FPOL1	FPOL2	FNLUT
-------------	-------	------------	------------	--------	------	------	---------	----------	-------	-------	-------	-------	-------	-------

1	ARROYO VIEJO	40	12	48	1.4	.	52	APRIL	1	7.67	11.750	19.52	.	.
2	ARROYO VIEJO	40	12	48	1.4	.	52	MARCH	1	3.15	6.130	9.28	.	.
3	ARROYO VIEJO	40	12	48	1.4	.	52	NOV	2	1.35	0.600	2.15	.	.
4	ARROYO VIEJO	40	12	48	1.4	.	52	OCT	3	1.12	1.330	2.95	.	.
5	CALABAZAS	56	14	30	9.1	.	70	APRIL	2	7.39	6.550	13.94	1.510	1.49
6	CALABAZAS	56	14	30	9.1	.	70	FEB	1	0.89	1.120	2.01	.	.
7	CALABAZAS	56	14	30	9.1	.	70	JULY	0	1.89	0.752	2.64	.	.
8	CALABAZAS	56	14	30	9.1	.	70	JULY	0	2.07	0.850	2.92	.	.
9	CALABAZAS	56	14	30	9.1	.	70	NOV	3	1.11	0.790	1.90	.	.
10	CALABAZAS	56	14	30	9.1	.	70	OCT	3	3.59	1.120	4.71	.	.
11	CASTRO VALLEY	56	12	32	3.3	.	68	APRIL	1	6.50	16.400	22.50	.	.
12	CASTRO VALLEY	56	12	32	3.3	.	68	FEB	1	1.05	1.010	2.06	.	.
13	CASTRO VALLEY	56	12	32	3.3	.	68	JULY	0	1.28	0.800	2.06	.	.
14	CASTRO VALLEY	56	12	32	3.3	.	68	NOV	2	0.39	0.590	1.37	.	.
15	CASTRO VALLEY	56	12	32	3.3	.	68	OCT	3	1.56	0.470	2.73	.	.
16	COLMA	38	21	41	7.5	.	59	APRIL	2	6.11	8.850	14.97	.	.

OBS	SALIP	SARDM	SPOL1	SPOL2	SNELUT	TSS	TDS	COND	PH	TURB	TOD	TALIP	TARM	TPOL1	TPOL2	TPOL12	TNELUT	HYDRO
-----	-------	-------	-------	-------	--------	-----	-----	------	----	------	-----	-------	------	-------	-------	--------	--------	-------

1	.	.	.	.	.	157.00	239	230	6.55	45.0	.	.	.	.	.	.	.
2	.	.	.	.	.	28.40	.	160	7.70	25.0	6	.	.	.	.	.	.
3	.	.	.	.	.	378.00	530	200	7.10	50.0	11	.	.	.	.	.	.
4	.	.	.	.	.	44.00	450	350	8.00	50.0	.	.	.	.	.	.	.
5	0.615	0.79	2.91	1.63	1.36	67.40	481	295	6.70	32.0	.	2.525	2.39	4.58	1.720	6.300	2.75	1.515
6	.	.	.	.	.	1436.00	276	145	7.10	50.0	9	.	.	.	.	.	.
7	.	.	.	.	.	2.30	436	600	8.30	2.0	.	.	.	.	.	.	.
8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
9	.	.	.	.	.	487.00	692	180	7.60	50.0	10	.	.	.	.	.	.
10	.	.	.	.	.	2.30	359	275	7.30	17.0	.	.	.	.	.	.	.
11	.	.	.	.	.	72.80	175	135	6.40	31.0	.	.	.	.	.	.	.
12	.	.	.	.	.	1101.00	251	130	7.10	50.0	9	.	.	.	.	.	.
13	.	.	.	.	.	0.99	648	900	7.85	1.5	.	.	.	.	.	.	.
14	.	.	.	.	.	422.00	586	260	7.10	50.0	8	.	.	.	.	.	.
15	.	.	.	.	.	37.00	605	650	8.00	50.0	.	.	.	.	.	.	.
16	.	.	.	.	.	13.30	1007	800	8.00	13.0	.	.	.	.	.	.	.

OBS	PHYDRO	THYDRO	FHYDRO	FNLUT	FALIP	FAROM	TPOL	FPOL	TOCRS	TOCRP	TOCR	FRATIO	GRATIO	TRATIO
-----	--------	--------	--------	-------	-------	-------	------	------	-------	-------	------	--------	--------	--------

1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
2	.	.	.	.	.	.	.	.	1.9048	0.9738	0.64655	.	.	.
3	.	.	.	.	.	.	.	.	6.1481	13.7500	5.11623	.	.	.
4	.	.	.	.	.	.	.	.	.	.	.	.	.	.
5	3.400	4.915	0.352582	0.197274	0.161133	0.171449	9.050	0.645211	.	.	.	.	.	.
6	.	.	.	.	.	.	.	.	10.1124	8.8757	4.47761	.	.	.
7	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8	.	.	.	.	.	.	.	.	.	.	.	.	.	.
9	.	.	.	.	.	.	.	.	9.0090	12.8562	5.23515	.	.	.
10	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12	.	.	.	.	.	.	.	.	8.5714	8.5109	4.75553	.	.	.
13	.	.	.	.	.	.	.	.	.	.	.	.	.	.
14	.	.	.	.	.	.	.	.	20.5126	8.0503	5.87842	.	.	.
15	.	.	.	.	.	.	.	.	.	.	.	.	.	.
16	.	.	.	.	.	.	.	.	.	.	.	.	.	.

1SAS 15:43 FRIDAY, SEPTEMBER 27, 1985 2

OBS STATION	RESID	COMM	UNDEV	ROADS	AREA	FRCOMM	DATE	TYPE	OIL_SOL	OIL_PART	OIL_T	FALIP	PAROM	FPOL1	FPOL2	FNELUT
17 COLMA	38	21	41	7.5	.	59	FEB 2	1.36	1.980	3.340	1.290	0.40	0.29	0.000	-0.06	
18 COLMA	38	21	41	7.5	.	59	JULY 0	3.98	7.460	11.440	6.500	0.39	0.59	0.040	-0.06	
19 COLMA	38	21	41	7.5	.	59	MAR .	.	.	.	.	.	.	.	.
20 COLMA	38	21	41	7.5	.	59	MARCH 1	2.85	4.590	7.440	3.010	0.41	.	.	0.19	
21 COLMA	38	21	41	7.5	.	59	NOV 3	1.18	0.530	1.710	0.250	0.18	0.13	0.000	-0.03	
22 COLMA	38	21	41	7.5	.	59	OCT 3	1.50	1.560	3.060	0.560	0.38	0.63	0.000	-0.11	
23 COLMA	38	21	41	7.5	.	59	OCT 3	1.61	1.570	3.180	.	.	.	.	.
24 CRANDALL	44	15	41	1.5	.	59	APRIL 2	7.91	3.200	11.110	0.580	0.36	0.65	0.895	0.72	
25 CRANDALL	44	15	41	1.5	.	59	FEB 1	1.28	1.500	2.780	.	.	.	.	.
26 CRANDALL	44	15	41	1.5	.	59	NOV 2	1.18	1.730	2.910	.	.	.	.	.
27 CRANDALL	44	15	41	1.5	.	59	OCT 3	2.66	1.910	3.670	.	.	.	.	.
28 ELMHURST	58	34	8	0.0	.	92	APRIL 1	10.11	10.780	20.500	.	.	.	.	.
29 ELMHURST	58	34	8	0.0	.	92	FEB .	.	.	.	.	.	.	.	.
30 ELMHURST	58	34	8	0.0	.	92	JULY 0	1.60	5.430	7.030	2.900	0.68	0.84	0.230	0.58	
31 ELMHURST	58	34	8	0.0	.	92	MAR .	.	.	.	.	.	.	.	.
32 ELMHURST	58	34	8	0.0	.	92	MARCH 2	1.51	1.030	2.540	.	.	.	.	.
OBG SALIP SAROM SPOL1 SPOL2 SNELUT	TSS	TDS	COND	PH	TURB	TOC	TALIP	TAROM	TPOL1	TPOL2	TPOL12	TNELUT	SHYDRO	PHYDRO		
17 0.39 0.29 0.65 0.00 0.03	39.00	671	650	7.30	50.0	11	1.620	0.69	.	.	0.340	-0.05	0.68	1.690		
18 1.87 0.38 1.50 0.03 0.20	34.70	1396	1500	8.20	23.0	.	6.370	0.77	2.09	0.070	2.180	0.14	2.25	6.690		
19 . . . . .	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
20 1.71 0.21 . . -0.14	12.40	.	200	7.60	12.0	6	4.720	0.62	.	.	.	0.05	1.92	3.420		
21 0.24 0.27 0.31 0.00 -0.14	24.20	763	750	7.80	26.0	10	0.490	0.45	.	.	0.540	-0.17	0.51	0.430		
22 0.31 0.11 0.71 0.42 -0.05	12.00	1250	900	8.10	19.0	.	0.670	0.49	.	.	1.740	-0.16	0.42	0.540		
23 . . . . .	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
24 0.22 0.17 2.57 2.63 2.57	83.40	1097	1100	7.65	39.0	.	0.800	0.53	3.21	3.725	6.945	3.29	0.39	0.940		
25	252.00	110	100	6.20	50.0	6	.	.	.	.	.	.	.	.	.
26	130.00	183	120	7.50	53.0	7	.	.	.	.	.	.	.	.	.
27	76.00	324	300	7.70	50.0	.	.	.	.	.	.	.	.	.	.
28	31.90	135	60	6.00	15.0	.	.	.	.	.	.	.	.	.	.
29 . . . . .	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
30 0.25 0.23 0.75 0.05 0.37	48.40	359	500	7.45	16.0	.	3.150	1.11	1.59	0.280	1.870	0.95	0.46	3.780		
31 . . . . .	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
32	4.10	.	900	7.40	20.0	4	.	.	.	.	.	.	.	.	.
OBG HYDRO PHYDRO FNELUT	FALIP	PAROM	TPOL	FPOL	TOCRS	TOCRP	TOCR	PFATI0	SRATI0	TRATI0						
17 2.370 0.709581 -0.014970 0.502994 0.206587	0.890	0.266467	8.0852	5.5556	3.2934	5.2	6.4	5.6636								
18 9.140 0.779551 0.012228 0.731643 0.067308	2.300	0.201049	.	.	.	6.9	1.1	0.9696								
19 . . . . .	.	.	.	.	.	6.5	7.9	.	.	.	.	.	.	.	.
20 5.340 0.717742 0.006720 0.634409 0.083333	.	.	2.1453	1.3072	0.8065	.	.	.	.	.	.	.	.	.	.
21 0.740 0.549708 -0.099415 0.286550 0.261158	0.770	0.450292	8.4746	18.8679	5.6460	4.0	6.5	5.7251								
22 1.360 0.444444 -0.052288 0.284314 0.160131	1.180	0.385621	.	.	.	7.4	7.9	7.6451								
23 . . . . .	.	.	.	.	.	7.4	7.9	7.6531							
24 1.330 0.119712 0.296130 0.072007 0.047705	10.235	0.921242	.	.	.	5.1	5.9	5.6656								
25	4.6675	4.0000	2.1583	.	.	.	.	.	.	.	.	.	.	.	.
26	5.9322	4.0462	2.4055	.	.	.	.	.	.	.	.	.	.	.	.
27 . . . . .	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28 . . . . .	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
29 . . . . .	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
30 4.260 0.605974 0.135135 0.448080 0.157895	2.620	0.401138	.	.	.	3.1	2.6	2.7852								
31 . . . . .	.	.	.	.	.	1.4	2.5	.	.	.	.	.	.	.	.
32 . . . . .	.	.	.	.	2.6490	3.8805	1.5748	.	.	.	.	.	.	.	.

15:43 FRIDAY, SEPTEMBER 27, 1985 3

OBG STATION RESID COMM UNDEV ROADS AREA FRCOMM DATE TYPE OIL_SOL OIL_PART OIL_T FALIP PAROM FPOL1 FPOL2 FNELUT

363 STATION	RESID	COMM	UNDEV	ROADS	AREA	PFCOMM	DATE	TYPE	OIL_EBL	OIL_FART	OIL_T	FALIP	FAROM	FPOL1	FPOL2	FHSLUT		
33 ELMHURST	58	34	8	0.0	.	92	MARCH	1	6.45	18.770	25.220	13.420	0.33	.	.	0.98		
34 ELMHURST	58	34	8	0.0	.	92	NOV	2	2.58	5.110	7.690	3.220	0.61	0.56	0.000	0.73		
35 ELMHURST	58	34	8	0.0	.	92	NOV	2	2.90	5.570	8.470	.	.	.	.	.
36 ELMHURST	58	34	8	0.0	.	92	OCT	3	4.32	4.620	8.940	2.750	0.48	0.68	0.130	0.38		
37 ELMHURST	58	34	8	0.0	.	92	OCT	3	5.12	5.320	10.440	.	.	.	.	.
38 ELMHURST	58	34	8	0.0	.	92	1	.	.	.	.	.	.	.	.	.
39 ELMHURST	58	34	8	0.0	.	92	2	.	.	.	.	.	.	.	.	.
40 ELMHURST	58	34	8	0.0	.	92	24	.	.	.	.	.	.	.	.	.
41 ELMHURST	58	34	8	0.0	.	92	3	.	.	.	.	.	.	.	.	.
42 ELMHURST	58	34	8	0.0	.	92	4	.	.	.	.	.	.	.	.	.
43 ELMHURST	58	34	8	0.0	.	92	5	.	.	.	.	.	.	.	.	.
44 ELMHURST	58	34	8	0.0	.	92	6	.	.	.	.	.	.	.	.	.
45 GLEN ECHO	51	14	35	0.0	.	65	APRIL	1	6.20	5.710	13.900	.	.	.	.	.
46 GLEN ECHO	51	14	35	0.0	.	65	FEB	1	1.03	1.610	2.640	.	.	.	.	.
47 GLEN ECHO	51	14	35	0.0	.	65	JULY	0	0.70	0.970	1.670	.	.	.	.	.
48 GLEN ECHO	51	14	35	0.0	.	65	NOV	1	2.15	11.000	13.150	.	.	.	.	.
363 SALIP SAROM SPOL1 SPOL2 SHLUT	TSS	TDS	COND	PH	TURB	TOC	TALIP	TAROM	TPOL1	TPOL2	TPOL12	THLUT	SHLUT	PHYDRO	PHYDRO			
33	2.51	0.25	.	0.310	204.00	.	50	7.60	50.0	13	15.930	0.58	.	.	1.290	2.76	12.750	
34	0.33	0.13	2.07	0.00	0.500	18.80	214	220	7.00	42.0	10	3.550	0.74	.	2.650	1.220	0.4%	3.630
35	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
36	1.78	0.52	1.66	0.06	0.300	30.00	470	400	7.30	12.5	.	4.530	1.00	.	2.540	0.650	2.31	3.230
37	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
38	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
39	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
40	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
41	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
42	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
43	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
44	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
45	.	.	.	.	.	38.60	176	110	7.00	4.5	.	.	.	.	.	.	.	.
46	.	.	.	.	.	33.00	190	185	7.20	26.0	7	.	.	.	.	.	.	.
47	.	.	.	.	.	2.24	.	370	7.60	3.0	.	.	.	.	.	.	.	.
48	.	.	.	.	.	125.00	127	80	6.90	34.0	5	.	.	.	.	.	.	.
363 THYDRO PHYDRO	FHSLUT	FALIP	FAROM	TPOL	FPOL	TOCRS	TOCRP	TOCR	PRATIO	SRATIO	TRATIO							
33	16.510	0.654639	0.051150	0.631642	0.022998	.	.	2.0155	0.6926	0.5155	.	.	.	.	.	.	.
34	4.290	0.557867	0.159949	0.461638	0.096229	3.860	0.501951	3.8760	1.9567	1.3004	1.6	4.9	2.7072	.	.	.	.
35	.	.	.	.	.	.	.	.	.	.	.	1.6	4.9	2.7259	.	.	.	.
36	5.530	0.616568	0.076063	0.506711	0.111657	3.220	0.360179	.	.	.	.	1.1	1.9	1.4866	.	.	.	.
37	.	.	.	.	.	.	.	.	.	.	.	1.1	1.9	1.4923	.	.	.	.
38	.	.	.	.	.	.	.	.	.	.	.	3.7	3.8	.	.	.	.	.
39	.	.	.	.	.	.	.	.	.	.	.	1.3	1.4	.	.	.	.	.
40	.	.	.	.	.	.	.	.	.	.	.	3.4	0.7	.	.	.	.	.
41	.	.	.	.	.	.	.	.	.	.	.	1.7	2.4	.	.	.	.	.
42	.	.	.	.	.	.	.	.	.	.	.	1.6	3.3	.	.	.	.	.
43	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
44	.	.	.	.	.	.	.	.	.	.	.	1.9	7.6	.	.	.	.	.
45	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
46	.	.	.	.	.	.	.	6.7761	4.3478	2.8515	.	.	.	.	.	.	.	.
47	.	.	.	.	.	.	.	2.7256	0.4545	0.3802	.	.	.	.	.	.	.	.
48	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1548																		
363 STATION	RESID	COMM	UNDEV	ROADS	AREA	PFCOMM	DATE	TYPE	OIL_EBL	OIL_FART	OIL_T	FALIP	FAROM	FPOL1	FPOL2	FHSLUT		
49 GLEN ECHO	51	14	35	0.0	.	65	OCT	3	1.28	1.120	2.400	.	.	.	.	.	.	.
50 GUADALUPE	52	4	74	7.7	.	26	APRIL	2	10.54	7.210	17.750	2.410	1.09	2.702	1.660	0.160	.	.

51 GUADALUPE	22	4	74	7.7	.	26	FEB	1	1.40	3.890	5.290	.	.	.	.	.
52 GUADALUPE	22	4	74	7.7	.	26	JULY	0	0.75	0.875	1.620	.	.	.	.	.
53 GUADALUPE	22	4	74	7.7	.	26	NOV	2	1.17	1.410	2.580	.	.	.	.	.
54 GUADALUPE	22	4	74	7.7	.	26	OCT	3	6.57	3.130	9.700	.	.	.	.	.
55 MATERDERO	5	2	93	1.2	.	7	APRIL	2	3.34	4.220	7.560	0.535	1.59	0.42	0.297	1.36
56 MATERDERO	5	2	93	1.2	.	7	FEB	3	0.74	0.230	0.970	.	.	.	.	.
57 MATERDERO	5	2	93	1.2	.	7	FEB	3	0.68	0.250	0.930	.	.	.	.	.
58 MATERDERO	5	2	93	1.2	.	7	FEB	1	0.67	1.050	1.720	0.500	0.25	0.30	0.000	0.00
59 MATERDERO	5	2	93	1.2	.	7	JULY	0	0.50	0.825	1.125	.	.	.	.	.
60 MATERDERO	5	2	93	1.2	.	7	NOV	3	0.64	0.820	1.460	0.220	0.38	0.22	0.000	0.00
61 MATERDERO	5	2	93	1.2	.	7	OCT	3	1.75	0.550	2.350	0.190	0.19	0.09	0.110	0.00
62 NAPA	10	3	87	0.0	.	13	APRIL	3	0.90	0.750	1.650	.	.	.	.	.
63 NAPA	10	3	87	0.0	.	13	FEB	1	0.55	0.150	0.700	.	.	.	.	.
64 NAPA	10	3	87	0.0	.	13	JULY	0	0.62	0.580	1.300	.	.	.	.	.

OBS	SALIP	SAREM	SPOL1	SPOL2	SNELUT	TSS	TDS	COND	PH	TURB	TOC	TALIP	TACRM	TPOL1	TPOL2	TPOL12	TNELUT	SHYDRO	PHYDRO
-----	-------	-------	-------	-------	--------	-----	-----	------	----	------	-----	-------	-------	-------	-------	--------	--------	--------	--------

49	.	.	.	.	.	24.00	330	400	8.20	9.5	.	.	.	.	.	.	.	.	.
50	1.030	2.440	3.19	2.44	1.440	105.00	191	155	6.30	42.0	.	3.440	3.530	5.21	4.120	9.330	1.440	3.47	3.500
51	.	.	.	.	.	158.00	114	115	7.30	50.0	6	.	.	.	.	.	.	.	.
52	.	.	.	.	.	19.90	472	550	7.50	12.5	.	.	.	.	.	.	.	.	.
53	.	.	.	.	.	26.80	158	115	7.30	46.0	6	.	.	.	.	.	.	.	.
54	.	.	.	.	.	31.00	210	125	6.54	41.0	.	.	.	.	.	.	.	.	.
55	0.410	0.750	0.75	0.99	0.440	25.80	1049	670	7.50	16.0	.	0.945	2.340	1.17	1.287	2.457	1.520	1.16	2.125
56	.	.	.	.	.	5.00	851	800	7.20	21.0	9	.	.	.	.	.	.	.	.
57	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
58	0.250	0.150	0.27	0.00	0.000	117.00	490	435	7.10	50.0	13	0.750	0.400	.	.	0.570	0.000	0.40	0.750
59	.	.	.	.	.	1.62	3114	2750	8.00	1.0	.	0.510	0.230	0.31	0.070	.	-0.010	.	.
60	0.100	0.260	0.28	0.00	0.000	21.00	652	550	8.00	36.0	12	0.320	0.640	.	.	0.500	0.000	0.36	0.600
61	0.090	0.220	1.13	0.05	0.260	6.30	1350	1100	7.90	9.0	.	0.230	0.410	.	.	1.220	0.260	0.31	0.380
62	.	.	.	.	.	19.10	234	210	7.00	11.0	.	.	.	.	.	.	.	.	.
63	.	.	.	.	.	3558.00	206	70	7.00	50.0	9	.	.	.	.	.	.	.	.
64	.	.	.	.	.	4.35	377	350	7.30	3.0	.	.	.	.	.	.	.	.	.

OBS	THYDRO	PHYDRO	FNELUT	FALIP	FAROM	TPOL	FPOL	TOCRS	TOCRP	TOCR	FRATIO	SPATIO	TRATIO
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49			
50	6.970	0.392676	0.081127	0.193803	0.196873	10.770	0.806761	.	.	.	9.4	9.9	9.6969		
51	4.2857	1.5424	1.1342		
52	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
53	.	.	.	.	.	.	.	5.1262	4.2553	2.3256	.	.	.	.	.	.	.	.	.	.
54	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
55	3.285	0.434524	0.240741	0.125000	0.309524	4.277	0.565741	.	.	.	22.0	13.9	18.4214	.	.	.	.	.	.	.
56	.	.	.	.	.	.	.	12.1622	39.1304	9.2784	25.5	26.1	25.9577	.	.	.	.	.	.	.
57	23.5	26.1	25.9387	
58	1.150	0.668605	0.000000	0.436047	0.232558	0.570	0.331395	19.4030	12.5810	7.5581	25.5	26.1	25.7337	
59	0.740	0.657778	-0.008389	0.453333	0.204444
60	0.980	0.657534	0.000000	0.219178	0.438356	0.500	0.342466	18.7500	14.6341	8.2192	31.3	44.0	36.8871
61	0.690	0.296137	0.111583	0.120172	0.175966	1.420	0.635193	.	.	.	24.5	17.5	19.2425
62	
63	16.3838	60.0000	12.8571
64	

1946 15:45 FRIDAY, SEPTEMBER 27, 1965 5

OBS	STATION	RESID	COMM	UNDEV	ROADS	AREA	PRCOMM	DATE	TYPE	OIL_GOL	OIL_PART	OIL_T	FALIP	FAROM	FPOL1	FPOL2	FNELUT
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65	NAPA	10	3	87	0.0	.	13	NOV	1	0.56	0.770	1.77
66	NAPA	10	3	87	0.0	.	13	OCT	1	4.09	3.580	7.65
67	FINE-GALLINDA	23	5	72	0.0	.	28	APRIL	2	3.10	1.320	4.42
68	FINE-GALLINDA	23	5	72	0.0	.	28	MARCH	1	1.11	0.540	1.65	.	.	.	.	.	.	.	.	.

DBS SALIP SAROM SPOL1 SPOL2 SNETLT TSS TDS COND PH TURB TOC TALIP TARDI TPOL1 TPOL2 TEOL12 TNETLT SHYPRO

65	.	.	.	.	.	4630.00	262	80	7.00	50.0	11	.	.	.	.	.	.	.	.
66	.	.	.	.	.	45.50	108	45	6.60	28.0	.	.	.	.	.	.	.	.	.	.
67	.	.	.	.	.	6.98	623	750	7.90	3.0	.	.	.	.	.	.	.	.	.	.
68	.	.	.	.	.	7.30	.	400	7.60	9.0	4	.	.	.	.	.	.	.	.	.
69	.	.	.	.	.	250.00	289	205	7.30	50.0	6	.	.	.	.	.	.	.	.	.
70	.	.	.	.	.	109.00	145	135	6.55	50.0	.	.	.	.	.	.	.	.	.	.
71	.	.	.	.	.	4.60	232	170	6.70	3.0	.	.	.	.	.	.	.	.	.	.
72	.	.	.	.	.	30.00	190	160	6.30	24.0	11	.	.	.	.	.	.	.	.	.
73	.	.	.	.	.	1.50	484	490	7.20	1.5	.	.	.	.	.	.	.	.	.	.
74	.	.	.	.	.	75.20	62	48	7.10	38.0	5	.	.	.	.	.	.	.	.	.
75	.	.	.	.	.	31.70	80	90	6.51	48.0	.	.	.	.	.	.	.	.	.	.
76	.	.	.	.	.	3.64	289	295	7.40	6.0	.	.	.	.	.	.	.	.	.	.
77	0.280	0.170	0.24	0.00	0.000	717.00	243	135	7.10	50.0	10	0.650	0.450	.	.	0.82	0.620	0.45	.	.	
78	15.00	149	210	7.20	36.0	6
79	0.150	0.290	0.57	0.11	0.095	11.82	342	460	7.85	1.5	.	0.350	0.650	0.73	0.17	0.60	0.115	0.44	.	.	
80	0.100	0.150	0.15	0.00	0.060	12.60	270	80	7.20	50.0	10	0.550	0.810	.	.	0.61	0.152	0.25	.	.	

DBS HYDRO THYDRO EHYDRO ENELUT FALIP FAROM TPOL FEOL TCE6S IOCNP ICSEB ESBIO ESBIO TESTA

65	.	.	.	.	.	.	.	.	19.5427	14.2357	8.27058	.	.
66	.	.	.	.	.	.	.	.	3.6036	7.4074	2.42424	.	.
67	.	.	.	.	.	.	.	.	5.7372	3.8482	2.30789	.	.
68	.	.	.	.	.	.	.	.	.	.	.	.	.
69	.	.	.	.	.	.	.	.	.	.	.	.	.
70	.	.	.	.	.	.	.	.	.	.	.	.	.
71	.	.	.	.	.	.	.	.	.	.	.	.	.
72	.	.	.	.	.	.	.	11.4583	5.2133	3.58306	.	.	.
73	.	.	.	.	.	.	.	.	.	.	.	.	.
74	.	.	.	.	.	.	.	2.7722	0.2800	0.61281	.	.	.
75	.	.	.	.	.	.	.	.	.	.	.	.	.
76	.	.	.	.	.	.	.	.	.	.	.	.	.
77	0.66	1.11	0.559231	0.010256	0.3356462	0.233769	0.640	0.430769	14.4728	7.9185	5.11321	13.4	12.7	13.2231
78	33.3333	4.7619	4.15567	13.4	12.9	12.3378
79	0.53	1. 1	0.557463	0.052239	0.164179	0.347284	1.005	0.500000	.	.	.	12.6	12.5	12.7035
80	1.11	1. 1	0.558651	0.068670	0.226052	0.347639	1.170	0.502146	21.7391	5.3476	4.13185	12.5	11.7	12.5523

SES STATION RESID COMM UNDEV ROAD5 AERF FRCMM DATE TYPE OIL_BOL OIL_PART OIL_T PALIP_ELCOM EFLC1_EFLC2

67	SLEEPY HOLLOW	26	0	74	0	.	26	4	.	.	.	.	.	.	.	.	.
88	SLEEPY HOLLOW	26	0	74	0	.	26	5	.	.	.	.	.	.	.	.	.
89	SLEEPY HOLLOW	26	0	74	0	.	26	6	.	.	.	.	.	.	.	.	.
90	SONOMA	2	0	98	0	.	2	APRIL	3	1.09	1.33	2.42	.	.	.	.	.
91	SONOMA	2	0	98	0	.	2	FEB	1	0.40	1.03	1.43	.	.	.	.	.
92	SONOMA	2	0	98	0	.	2	JULY	0	0.46	0.48	0.94	.	.	.	.	.
93	SONOMA	2	0	98	0	.	2	NOV	1	0.54	0.76	1.70	.	.	.	.	.
94	SONOMA	2	0	98	0	.	2	OCT	1	0.87	0.36	1.22	.	.	.	.	.
95	TEMESCAL	53	13	34	8	.	66	APRIL	1	7.26	11.90	19.20	.	.	.	.	.
96	TEMESCAL	53	13	34	8	.	66	APRIL	3	0.94	1.56	2.50	0.89	0.26	.	.	.

DBS PNELUT SALIP SAROM SPOL1 SPOL2 SNELUT TSS TDS COND PH TURB TOC TALIP TAROM TPOL1 TPOL2 TPOL12 TNELUT HYDRO

81	0.23	0.110	0.160	0.82	0.00	0.55	433.00	211	299	7.5	50.0	.	0.710	0.400	.	.	1.73	0.78	0.27
82	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
83	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
84	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
85	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
86	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
87	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
88	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
89	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
90	.	.	.	.	.	.	23.10	227	115	7.4	19.0	.	.	.	.	.	.	.	.
91	.	.	.	.	.	.	862.00	167	55	6.1	59.0	5	.	.	.	.	.	.	.
92	.	.	.	.	.	.	1.80	280	335	8.0	1.5	.	.	.	.	.	.	.	.
93	.	.	.	.	.	.	651.00	167	65	7.2	50.0	8	.	.	.	.	.	.	.
94	.	.	.	.	.	.	2.80	241	290	7.8	14.0	.	.	.	.	.	.	.	.
95	.	.	.	.	.	.	30.90	150	70	6.4	15.0	.	.	.	.	.	.	.	.
96	0.01	0.510	0.200	.	.	0.10	5.70	150	8.0	3.0	3	1.200	0.460	.	.	.	0.11	0.51	.

DBS HYDRO THYDRO FHYDRO FNELUT FALIP FAROM TPOL FFOL TDSRS TDSRP TDSR TFRATIO SFRACTION TRATIO

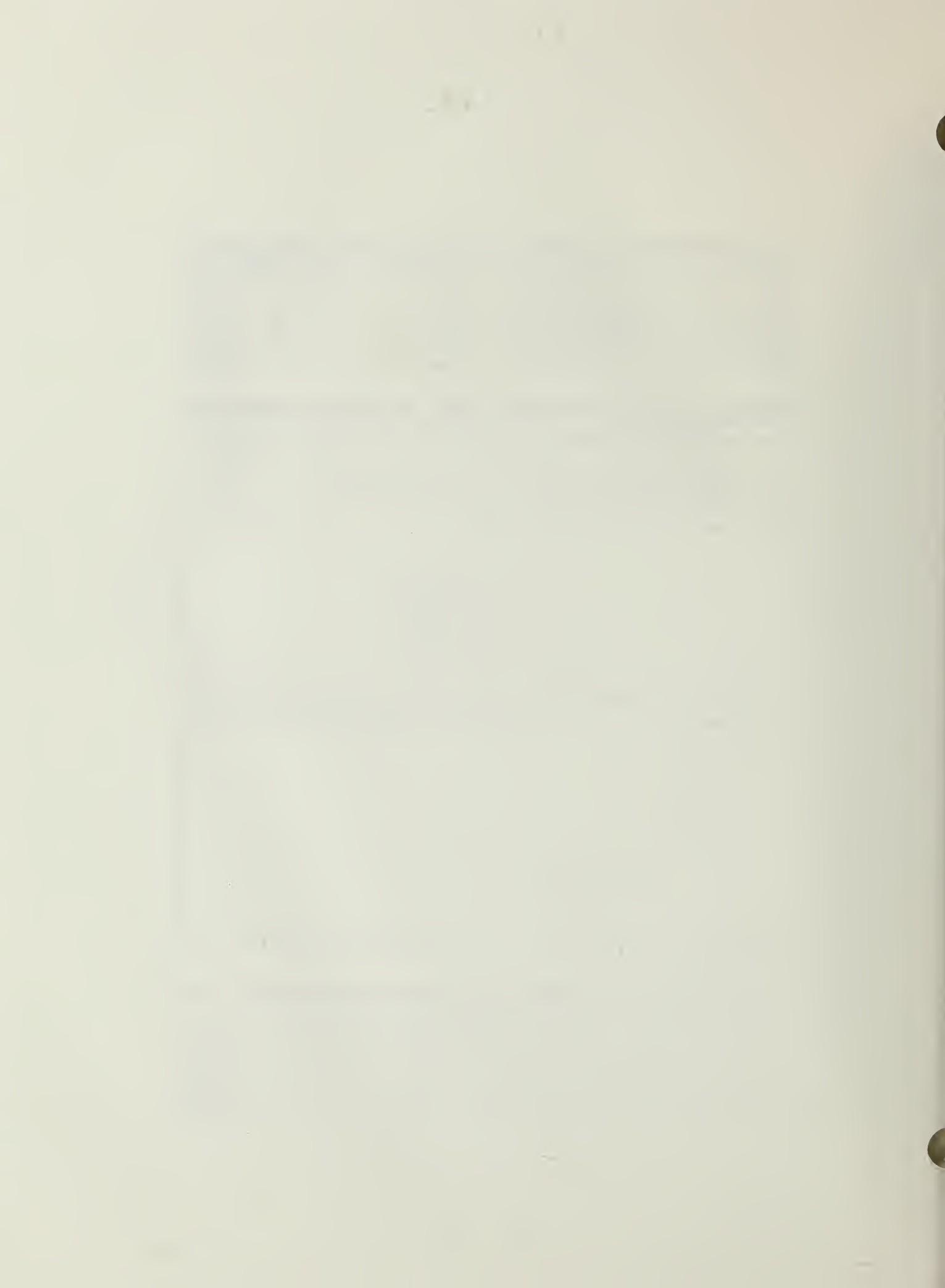
81	0.84	1.11	0.305765	0.214876	0.195592	0.110193	2.51	0.691460	.	.	.	.	.	16.5	18.0	17.1777	.	.	.
82	.	.	.	.	.	.	.	.	.	.	.	.	.	16.5	18.0	17.0540	.	.	.
83	.	.	.	.	.	.	.	.	.	.	.	.	.	14.4	16.2	.	.	.	.
84	.	.	.	.	.	.	.	.	.	.	.	.	.	15.5	3.4	.	.	.	.
85	.	.	.	.	.	.	.	.	.	.	.	.	.	17.4	12.9	.	.	.	.
86	.	.	.	.	.	.	.	.	.	.	.	.	.	15.7	15.0	.	.	.	.
87	.	.	.	.	.	.	.	.	.	.	.	.	.	24.3	15.1	.	.	.	.
88	.	.	.	.	.	.	.	.	.	.	.	.	.	16.5	17.2	.	.	.	.
89	.	.	.	.	.	.	.	.	.	.	.	.	.	14.7	14.0	.	.	.	.
90	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
91	.	.	.	.	.	.	.	.	.	20.0000	7.7670	5.59441	.	.	.	.	.	.	.
92	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
93	.	.	.	.	.	.	.	.	.	8.5106	10.5233	4.70533	.	.	.	.	.	.	.
94	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
95	.	.	.	.	.	.	.	.	.	.	.	.	.	1.0	1.5	1.1870	.	.	.
96	1.15	1.66	0.664000	0.044000	0.480000	0.184000	.	.	.	3.1915	1.7231	1.200000	1.0	1.5	1.1230

15:43 FRIDAY, SEPTEMBER 27, 1985 7

065 STATION RESID COMM UNDEV ROADS AREA FRCMM DATE TYPE OIL_SOL OIL_FART OIL_T FALIP FAROM FFOL1 FFOL2 FNELUT

97	TEMESCAL	53	13	34	8	.	66	FEB	2	2.67	6.30	8.97	4.65	0.41	0.97	0.00	0.07	.	.
98	TEMESCAL	53	13	34	8	.	66	FEB	2	3.01	6.11	8.12	.	.	.	.	.	.	.
99	TEMESCAL	53	13	34	8	.	66	JULY	0	1.29	1.69	2.55	0.41	0.55	0.52	0.21	0.00	.	.
100	TEMESCAL	53	13	34	8	.	66	MARCH	1	3.51	9.25	12.76	7.40	0.29	.	.	0.14	.	.
101	TEMESCAL	53	13	34	8	.	66	NOV	1	3.19	43.72	46.91	23.63	2.10	9.81	0.66	2.58	.	.
102	TEMESCAL	53	13	34	8	.	66	NOV	1	2.75	40.31	43.07	.	.	.	.	.	.	.
103	TEMESCAL	53	13	34	8	.	66	OCT	1	1.75	1.65	2.80	0.67	0.26	0.67	0.04	-0.01	.	.
104	TEMESCAL	53	13	34	8	.	66	OCT	3	2.37	1.78	4.17	.	.	.	.	.	.	.

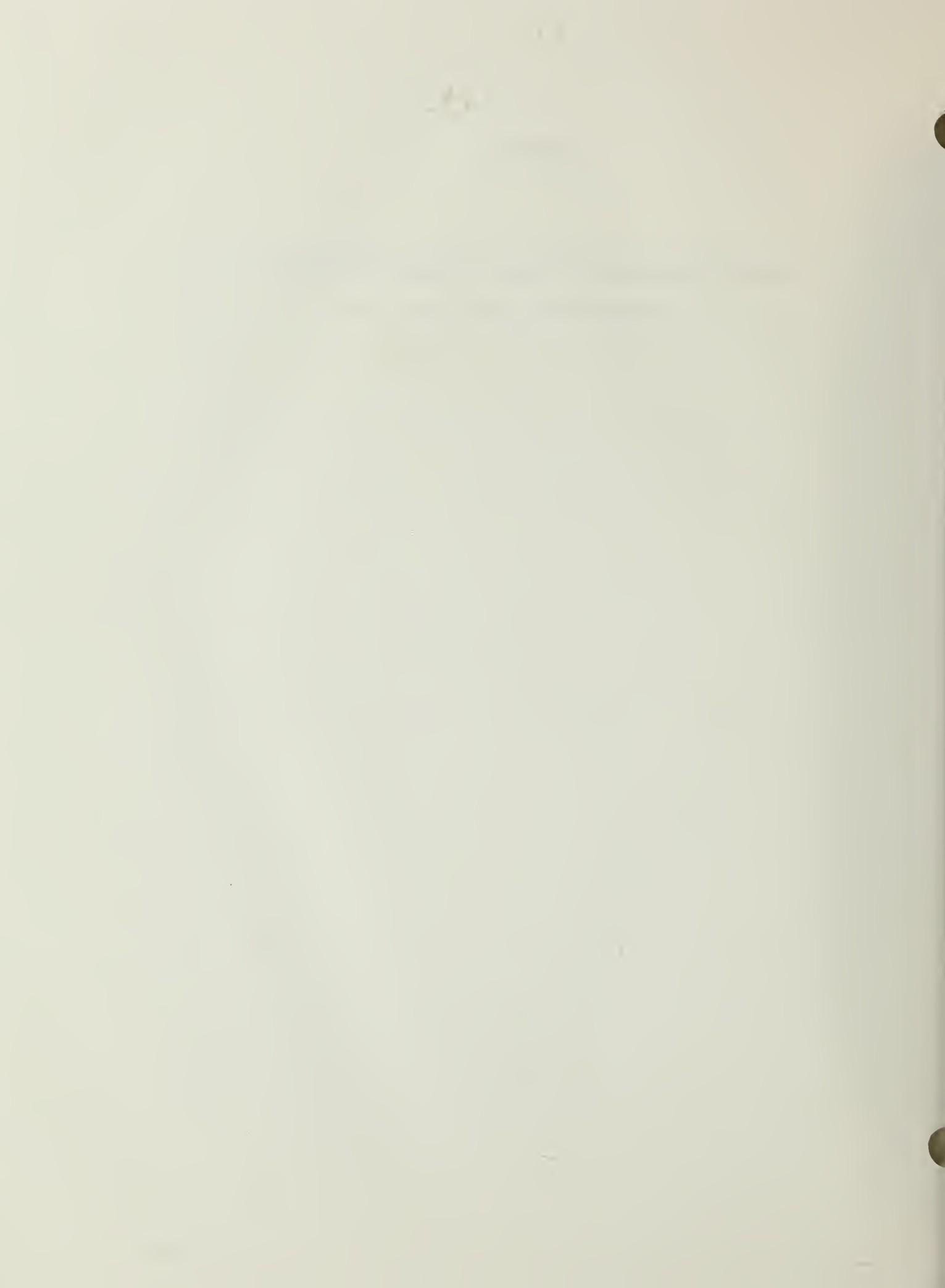
OBS	SALIP	SAGOM	SPOL1	SPOL2	SNELUT	TSS	TDS	COND	PH	TURB	TOC	TALIP	TAGOM	TPOL1	TPOL2	TPOL12	TNELUT	SHYDRO	PHYDRO
97	0.440	0.210	1.92	0.00	0.10	11.00	123	135	7.0	24.0	7	5.290	0.620	.	.	2.89	0.17	0.65	5.26
98	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.61	-0.02	0.43	0.96
99	0.215	0.215	0.73	0.15	-0.02	4.13	213	240	7.0	4.5	.	0.625	0.765	1.25	0.36	.	.	.	.
100	1.210	0.410	.	.	-0.01	20.10	.	150	7.6	25.0	7	8.610	0.700	.	.	.	0.13	1.62	7.67
101	0.670	0.420	1.99	0.00	-0.09	404.00	135	50	8.1	50.0	10	29.790	2.520	.	.	11.80	2.87	1.29	30.93
102	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.64	-0.01	0.46	1.15
103	0.310	0.150	0.97	0.52	0.00	3.00	320	350	7.7	4.0	.	1.180	0.430	.	.	.	.	.	.
104	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
OBS	THYDRO	FHYDRO	FNELUT	FALIP	FAGOM	TFOL	FFOL			T2CRS	T2CRP	T2CR					FRATIO	GRATIO	TRATIO
97	5.91	0.658863	0.0189521	0.589744	0.069119	3.06	0.741137	2.62172	1.11111	0.780379	0.8	2.0	1.15719	.	.	.	.	.	.
98	.	.	.	.	.	.	.	.	.	.	.	0.8	2.0	1.19605	.	.	.	.	.
99	1.39	0.466443	-0.0067114	0.209732	0.256711	1.59	0.532557	.	.	.	2.4	2.9	2.61644	.	.	.	.	.	.
100	9.31	0.729524	0.0101881	0.674765	0.054359	.	.	.	1.95430	0.75676	0.548589	1.0	1.0	1.00000	.	.	.	.	.
101	32.22	0.686547	0.0616073	0.633127	0.053720	14.69	0.313153	0.13480	0.22373	0.213174	0.2	0.2	0.20550	.	.	.	.	.	.
102	.	.	.	.	.	.	.	.	.	.	0.2	0.2	0.20541	.	.	.	.	.	.
103	1.61	0.427684	-0.0026316	0.310526	0.113158	1.83	0.426947	.	.	.	2.4	2.5	2.50263	.	.	.	.	.	.
104	.	.	.	.	.	.	.	.	.	.	2.4	2.5	2.48776	.	.	.	.	.	.



APPENDIX B

LISTING OF RUNOFF STATION MEANS AND SUMMARY STATISTICS

(See Table IV-1 for abbreviation key)



ISAS

16:02 FRIDAY, SEPTEMBER 27, 1985 1

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
STATION=ARROYO VIEJO									
RESID	4	40.00000000	0.00000000	40.00000000	40.00000000	0.00000000	160.0000000	0.000000	0.000
COMM	4	12.00000000	0.00000000	12.00000000	12.00000000	0.00000000	48.0000000	0.000000	0.000
UNDEV	4	48.00000000	0.00000000	48.00000000	48.00000000	0.00000000	192.0000000	0.000000	0.000
ROADS	4	1.40000000	0.00000000	1.40000000	1.40000000	0.00000000	5.6000000	0.000000	0.000
AREA	0	.	.	.	.	.	.	.	.
FRCOMM	4	52.00000000	0.00000000	52.00000000	52.00000000	0.00000000	208.0000000	0.000000	0.000
TYPE	4	1.75000000	0.95742711	1.00000000	3.00000000	0.47871755	7.0000000	0.916667	53.710
OIL_SOL	4	3.37250000	3.153269187	1.12000000	7.87000000	1.56634593	13.4900000	9.813753	92.559
OIL_FART	4	5.12750000	4.96207704	0.80000000	11.75000000	2.49103852	20.5100000	24.821092	57.164
OIL_T	4	8.50000000	8.07027054	2.15000000	19.62000000	4.03513527	34.0000000	65.129257	94.544
FALIP	0	.	.	.	.	.	.	.	.
PAROM	0	.	.	.	.	.	.	.	.
FPOL1	0	.	.	.	.	.	.	.	.
FPOL2	0	.	.	.	.	.	.	.	.
FNELUT	0	.	.	.	.	.	.	.	.
SALIP	0	.	.	.	.	.	.	.	.
SAROM	0	.	.	.	.	.	.	.	.
SPOL1	0	.	.	.	.	.	.	.	.
SPOL2	0	.	.	.	.	.	.	.	.
SNELUT	0	.	.	.	.	.	.	.	.
TSS	4	156.65000000	170.67305001	23.40000000	738.00000000	65.32552501	527.4000000	25128.250000	103.513
TDS	3	406.33333333	150.33407243	239.00000000	530.00000000	86.79541719	1219.0000000	21530.333333	36.373
COND	4	235.00000000	81.85352772	160.00000000	750.00000000	40.92676286	5-0.0000000	8700.000000	34.831
FH	4	7.53750000	0.64466985	6.55000000	8.00000000	0.71224452	59.1500000	0.415615	8.739
TURB	4	42.50000000	11.90352071	25.00000000	50.00000000	5.95119036	171.0000000	141.666667	28.006
TOC	2	8.50000000	3.53553391	6.00000000	11.00000000	2.50000000	17.0000000	12.500000	41.535
TALIP	0	.	.	.	.	.	.	.	.
TAROM	0	.	.	.	.	.	.	.	.
TPOL1	0	.	.	.	.	.	.	.	.
TPOL2	0	.	.	.	.	.	.	.	.
TPOL12	0	.	.	.	.	.	.	.	.
TNELUT	0	.	.	.	.	.	.	.	.
SHYDRO	0	.	.	.	.	.	.	.	.
PHYDRO	0	.	.	.	.	.	.	.	.
THYDRO	0	.	.	.	.	.	.	.	.
FHYDRO	0	.	.	.	.	.	.	.	.
FNELUT	0	.	.	.	.	.	.	.	.
FALIP	0	.	.	.	.	.	.	.	.
PAROM	0	.	.	.	.	.	.	.	.
TPOL	0	.	.	.	.	.	.	.	.
FFOL	0	.	.	.	.	.	.	.	.
TOCRS	2	5.02645503	4.41474075	1.90476190	2.14514815	7.12169712	10.0529101	15.489975	87.830
TOCRP	2	7.76437641	9.03060720	0.57679382	17.75000000	6.38560359	14.7267923	61.551656	122.525
TOCR	2	2.66141540	5.16057452	0.64655172	5.11627907	2.23436367	5.7623308	9.996221	109.688
PRATIO	0	.	.	.	.	.	.	.	.
SRATIO	0	.	.	.	.	.	.	.	.
TRATIO	0	.	.	.	.	.	.	.	.
ISAS							16:02 FRIDAY, SEPTEMBER 27, 1985		
VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.

STATION=CALABAZAS

RESID	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD. ERROR OF MEAN	BUS	VARIANCE	C.V.
STATION=CASTRO VALLEY									
FEBRD	5	56.0000000	0.0000000	56.0000000	56.0000000	0.0000000	335.0000000	0.00000	0.000
COMM	6	14.0000000	0.0000000	14.0000000	14.0000000	0.0000000	84.0000000	0.00000	0.000
UNDEV	6	30.0000000	0.0000000	30.0000000	30.0000000	0.0000000	180.0000000	0.00000	0.000
ROADS	6	9.1000000	0.0000000	9.1000000	9.1000000	0.0000000	54.8000000	0.00000	0.000
AREA	0	.	.	.	.	.	.	.	.
PRCOMM	6	70.0000000	0.0000000	70.0000000	70.0000000	0.0000000	420.0000000	0.00000	0.000
TYPE	6	1.5000000	1.37540488	0.0000000	3.0000000	0.56273143	9.0000000	1.90000	31.594
OIL_SOL	6	2.82333333	2.43121917	0.8700000	7.3500000	0.99254107	16.9400000	5.91083	56.112
OIL_PART	6	1.86366667	2.30147272	0.7500000	6.5500000	0.93957230	11.1800000	5.23678	103.442
OIL_T	6	4.68666667	4.64466863	1.9000000	17.7400000	1.89617803	28.1200000	21.57295	77.104
FALIP	1	1.9100000	.	1.9100000	1.9100000	.	1.9100000	.	.
FAROM	1	1.4500000	.	1.4500000	1.4500000	.	1.4500000	.	.
FPDL1	1	1.6700000	.	1.6700000	1.6700000	.	1.6700000	.	.
FFDL2	1	0.0900000	.	0.0900000	0.0900000	.	0.0900000	.	.
FNELUT	1	1.3700000	.	1.3700000	1.3700000	.	1.3700000	.	.
SALIP	1	0.6150000	.	0.6150000	0.6150000	.	0.6150000	.	.
SHADM	1	0.9200000	.	0.9200000	0.9200000	.	0.9200000	.	.
SPDL1	1	2.8100000	.	2.8100000	2.8100000	.	2.8100000	.	.
SPDL2	1	1.6500000	.	1.6500000	1.6500000	.	1.6500000	.	.
SNELUT	1	1.7400000	.	1.7400000	1.7400000	.	1.7400000	.	.
TES	5	179.0000000	613.9625553	2.0000000	1425.0000000	274.5715744	1975.0000000	37653.33510	155.874
TDS	5	443.8300000	156.7403857	275.0000000	612.0000000	214.4764757	2144.0000000	24567.70000	34.924
COND	5	159.0000000	179.63153773	145.0000000	600.0000000	66.33757511	1455.0000000	32267.50000	60.077
PH	5	7.4000000	0.6000000	6.7000000	8.7000000	0.11332316	37.0000000	0.36000	2.138
TURB	5	30.2000000	20.55709904	2.0000000	50.0000000	5.77227761	151.0000000	475.20000	65.354
TDC	2	8.5000000	0.70719678	8.0000000	10.0000000	0.5000000	19.0000000	0.50000	7.443
TALIP	1	2.5250000	.	2.5250000	2.5250000	.	2.5250000	.	.
THADM	1	2.3700000	.	2.3700000	2.3700000	.	2.3700000	.	.
TPDL1	1	4.5500000	.	4.5500000	4.5500000	.	4.5500000	.	.
TPDL2	1	1.7200000	.	1.7200000	1.7200000	.	1.7200000	.	.
TFCL12	1	6.3000000	.	6.3000000	6.3000000	.	6.3000000	.	.
THELUT	1	2.7500000	.	2.7500000	2.7500000	.	2.7500000	.	.
SHYDRO	1	1.5150000	.	1.5150000	1.5150000	.	1.5150000	.	.
PHYDRO	1	3.4000000	.	3.4000000	3.4000000	.	3.4000000	.	.
THYDRO	1	4.9150000	.	4.9150000	4.9150000	.	4.9150000	.	.
FHYDRO	1	0.35255250	.	0.35255250	0.35255250	.	0.35255250	.	.
FNELUT	1	0.19727463	.	0.19727463	0.19727463	.	0.19727463	.	.
FALIP	1	0.18113343	.	0.18113343	0.18113343	.	0.18113343	.	.
FAROM	1	0.17144907	.	0.17144907	0.17144907	.	0.17144907	.	.
TPDL	1	9.0500000	.	9.0500000	9.0500000	.	9.0500000	.	.
FPDL	1	0.64921090	.	0.64921090	0.64921090	.	0.6492109	.	.
TCRFB	2	7.55088428	0.78013555	7.0000000	13.11225536	1.55167527	17.1217456	0.61069	5.160
TCRFP	2	10.3497107	0.12051057	8.0000000	12.5582173	1.112125378	20.6935421	10.53021	31.570
TCFR	2	4.87035492	0.55546487	4.47761174	5.1631573	0.39277298	9.7407698	0.70354	11.405
PRATIO	0	.	.	.	.	.	.	.	.
BRATIO	0	.	.	.	.	.	.	.	.
TRATIO	0	.	.	.	.	.	.	.	.
LEAG							16:02 FRIDAY, SEPTEMBER 27, 1985	3	
STATION=CASTRO VALLEY									
FEBRD	5	56.0000000	0.0000000	56.0000000	56.0000000	0.0000000	330.0000000	0.00000	0.000
COMM	5	14.0000000	0.0000000	14.0000000	14.0000000	0.0000000	80.0000000	0.00000	0.000
UNDEV	5	30.0000000	0.0000000	30.0000000	30.0000000	0.0000000	180.0000000	0.00000	0.000
ROADS	5	9.1000000	0.0000000	9.1000000	9.1000000	0.0000000	54.8000000	0.00000	0.000
AREA	0	.	.	.	.	.	.	.	.

PRODM	5	68.00000000	0.00000000	68.00000000	68.00000000	0.00000000	340.00000000	0.00000	0.000
TYPE	5	1.40000000	1.14017543	0.00000000	1.00000000	0.50990195	7.00000000	1.30000	31.441
OIL_SOL	5	2.21600000	2.45200530	0.37000000	5.50000000	1.09657011	11.05000000	6.61273	110.650
OIL_PART	5	3.73400000	6.97207501	0.47000000	16.40000000	1.11800674	19.67000000	48.60783	177.226
OIL_T	5	6.14800000	9.37144973	1.37000000	22.70000000	4.15103973	59.74000000	87.62407	152.431
FALIP	0	.	.	.	.	.	.	.	.
FARM	0	.	.	.	.	.	.	.	.
FPOL1	0	.	.	.	.	.	.	.	.
FPOL2	0	.	.	.	.	.	.	.	.
PNELUT	0	.	.	.	.	.	.	.	.
SALIP	0	.	.	.	.	.	.	.	.
SAROM	0	.	.	.	.	.	.	.	.
SFCI1	0	.	.	.	.	.	.	.	.
SFCI2	0	.	.	.	.	.	.	.	.
SNELUT	0	.	.	.	.	.	.	.	.
TSS	5	328.75800000	464.51611040	0.93000000	1101.00000000	207.70751690	1833.77900000	215775.21682	142.159
TCS	5	405.00000000	221.37411773	125.00000000	646.00000000	57.00181514	2025.00000000	4706.50000	54.660
COND	5	415.00000000	344.27459970	150.00000000	500.00000000	152.98413157	2075.00000000	108525.00000	62.758
PH	5	7.27000000	0.64645971	5.40000000	8.00000000	0.17000000	16.45000000	0.42150	3.875
TURB	5	74.50000000	21.22478528	1.50000000	50.00000000	5.47210158	162.50000000	450.51000	55.151
TOC	2	8.50000000	0.70710678	8.10000000	9.00000000	0.53100000	17.10000000	0.51000	0.519
TALIP	0	.	.	.	.	.	.	.	.
TARM	0	.	.	.	.	.	.	.	.
TPOL1	0	.	.	.	.	.	.	.	.
TPOL2	0	.	.	.	.	.	.	.	.
TPOL12	0	.	.	.	.	.	.	.	.
TNELUT	0	.	.	.	.	.	.	.	.
SHYDRO	0	.	.	.	.	.	.	.	.
PHYDRO	0	.	.	.	.	.	.	.	.
THYDRO	0	.	.	.	.	.	.	.	.
FHYDRO	0	.	.	.	.	.	.	.	.
FNELUT	0	.	.	.	.	.	.	.	.
FALIP	0	.	.	.	.	.	.	.	.
FARM	0	.	.	.	.	.	.	.	.
TPOL	0	.	.	.	.	.	.	.	.
FFOL	0	.	.	.	.	.	.	.	.
TOCRS	2	14.54212454	8.44383522	8.57142557	20.5128205	5.37016937	27.0342491	71.23841	58.365
TOCRP	2	8.49584758	0.52657532	8.08080808	8.5105911	0.41504150	16.8916752	0.74451	5.319
TOCR	2	5.10417405	1.03973622	4.36863204	5.62754161	0.72524204	10.2063481	1.0811e	20.371
PRATIO	0	.	.	.	.	.	.	.	.
SRATIO	0	.	.	.	.	.	.	.	.
TRATIO	0	.	.	.	.	.	.	.	.
ISAS								16:02 FRIDAY, SEPTEMBER 27, 1985	
VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	S.V.

STATION=COLMA

RESID	8	35.00000000	0.00000000	15.00000000	38.00000000	0.00000000	304.00000000	0.00000	0.000
DEHM	8	21.00000000	0.00000000	21.00000000	21.00000000	0.00000000	168.00000000	0.00000	0.000
UNDEV	8	41.00000000	0.00000000	41.00000000	41.00000000	0.00000000	328.00000000	0.00011	0.000
ROADS	8	7.50000000	0.00000000	7.00000000	7.00000000	0.00000000	60.00000000	0.00000	0.000
AREA	0	.	.	.	.	.	.	.	.
PRODM	8	59.00000000	0.00000000	59.00000000	59.00000000	0.00000000	472.00000000	0.00000	0.000
TYPE	7	2.00000000	1.15470054	0.30000000	5.00000000	1.47647373	14.10000000	0.17773	37.772
OIL_SOL	7	2.25571429	1.62316555	1.15000000	2.11000000	0.87002721	11.50000000	0.12248	32.764
OIL_PART	7	3.73205714	3.21524782	0.55000000	8.36100000	1.22174448	25.55200000	0.11271	75.350
OIL_T	7	6.44257143	5.04637505	1.71000000	14.57100000	1.78774373	45.12000000	0.14651	52.225
FALIP	5	2.32200000	2.58365140	0.10000000	5.31000000	0.1-677583	11.51000000	0.51777	11.511

PARM	5	0.35200000	0.09679276	0.18000000	0.4100000	0.04326972	1.7600000	0.00937	27.500
PPOL1	4	0.41000000	0.24055491	0.13000000	0.6500000	0.12027746	1.6400000	0.05787	58.572
PPOL2	4	0.01000000	0.02000000	0.00000000	0.0400000	0.01600060	0.0400000	0.00049	200.000
PNELUT	5	-0.01800000	0.11987473	-0.11000000	0.1900000	0.05360970	-0.0900000	0.01437	-665.972
SALIP	5	0.90400000	0.81251462	0.24000000	1.8700000	0.36336758	4.5200000	0.66018	89.580
SARGM	5	0.25200000	0.1008995	0.11000000	0.3500000	0.04476666	1.2600000	0.01002	39.722
SPOL1	4	0.91750000	0.39390143	0.65000000	1.5000000	0.19695071	3.8700000	0.15516	42.972
SPOL2	4	0.11250000	0.20548723	0.00000000	0.4200000	0.10274361	0.4500000	0.04222	162.655
SNELUT	5	-0.02000000	0.14135970	-0.14000000	0.2000000	0.06348228	-0.1900000	0.02015	-709.753
TSS	6	22.68333333	11.95087032	12.00000000	39.0000000	4.87075741	176.1000000	142.34587	52.573
TDS	5	1017.40000000	309.13637767	671.00000000	1396.0000000	138.24999096	5087.0000000	95565.30000	30.135
COND	6	800.00000000	420.71367936	200.00000000	1500.0000000	171.75564037	4800.0000000	177000.00000	52.569
PH	6	7.83333333	0.33862467	7.30000000	8.2000000	0.13624294	47.0000000	0.11457	4.323
TURB	6	25.50000000	14.81552339	12.00000000	50.0000000	6.04841577	153.0000000	219.50000	56.100
TDC	3	9.00000000	2.64575131	6.00000000	11.0000000	1.52752523	27.0000000	7.00000	25.397
TALIP	5	3.22600000	3.32111579	0.45000000	8.7000000	1.48524947	16.1530000	11.05553	102.749
TAROM	5	0.60400000	0.13408952	0.45000000	0.7700000	0.05978666	3.0200000	0.01793	22.200
TFCL1	1	2.05000000	.	2.09000000	2.0900000	.	2.0900000	.	.
TFCL2	1	0.07000000	.	0.07000000	0.0700000	.	0.0700000	.	.
TFOL12	4	1.34500000	0.57512318	0.54000000	2.1600000	0.12756159	5.1350000	0.03377	42.760
TNELUT	5	-0.01800000	0.13405223	-0.17000000	0.1400000	0.05994398	-0.1900000	0.01777	-752.769
SHYDRO	5	1.13500000	0.66112136	0.42000000	2.2500000	0.35510518	5.7500000	0.74153	74.491
FHYDRO	5	2.67400000	2.61446553	0.45000000	8.3900000	1.18522453	10.3700000	5.35543	97.774
THYDRO	5	3.83000000	3.45004373	0.94000000	9.1400000	1.57356219	17.1500000	11.76520	69.557
FHYDRO	5	0.64405517	0.14358098	0.44444444	0.7338510	0.36421176	1.2204259	0.63362	22.292
FNELUT	5	-0.02754293	0.04656303	-0.09744520	0.0122376	0.02982564	-0.1477147	1.08217	-157.612
FALIP	5	0.48733188	0.20172369	0.15431173	0.7316454	0.09030302	2.4357794	0.04077	41.179
FARM	5	0.15310729	0.03247063	0.06730769	0.2431577	0.02658159	0.7285185	0.03680	52.571
TFOL	4	1.28500000	0.67821200	0.77000000	2.3000000	0.34910400	5.1470000	0.48780	54.726
FPOL	4	0.32553733	0.11127334	0.20104555	0.4562924	0.05639157	1.3321743	0.01272	24.611
TOCRS	3	6.22264157	3.57102610	2.10523516	8.4745763	2.661773288	13.5680747	12.75123	57.387
TOCRP	3	8.57866956	9.16194256	1.30716734	18.8679245	5.13965024	15.7320696	63.94120	106.621
TOCR	3	3.31572333	2.52082629	0.80645161	5.8479552	1.3553774	5.9478180	6.05457	76.021
PRATIO	6	5.23333333	2.50173273	0.90000000	7.4000000	1.02132811	31.4000000	6.25367	47.504
SRATIO	6	6.28333333	2.63693060	1.10000000	7.9000000	1.07654282	37.7000000	6.75367	41.368
TRATIO	5	5.53631841	2.73138467	0.96958042	7.6571447	1.22151245	37.6515921	7.46146	49.076
1SAS							16:02 FRIDAY, SEPTEMBER 27, 1985	5	

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD. ERROR OF MEAN	SUM	VARIANCE	C.V.
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STATION=CRANDALL									
FBID	4	44.00000000	0.00000000	44.00000000	44.0000000	0.00000000	176.0000000	0.00000	0.000
COMM	4	15.00000000	0.00000000	15.00000000	15.0000000	0.00000000	60.0000000	0.00000	0.000
UNDEV	4	41.00000000	0.00000000	41.00000000	41.0000000	0.00000000	164.0000000	0.00000	0.000
ROADS	4	1.50000000	0.00000000	1.50000000	1.5000000	0.00000000	6.0000000	0.00000	0.000
AREA	0								
FBCOMM	4	59.00000000	0.00000000	59.00000000	59.0000000	0.00000000	236.0000000	0.00000	0.000
TF-E	4	2.00000000	0.81647658	1.00000000	2.0000000	0.40614229	8.0000000	0.46667	40.625
OIL_SEL	4	3.03750000	3.174333851	1.19000000	7.3100000	1.55718529	13.0000000	10.07642	57.447
OIL_FART	4	1.85000000	0.94244763	1.01000000	2.0000000	0.47122162	7.4400000	0.82320	50.069
OIL_T	4	5.11750000	4.01427812	2.73000000	11.1100000	2.3711865	20.4700000	16.11483	72.441
FALIP	1	0.53000000	.	0.53000000	0.5800000	.	1.5300000	.	.
PARM	1	0.35000000	.	0.35000000	0.3500000	.	0.3500000	.	.
PPOL1	1	0.65000000	.	0.65000000	0.6500000	.	0.6500000	.	.
PPOL2	1	0.55500000	.	0.55500000	0.5550000	.	0.5550000	.	.
FNELUT	1	0.71000000	.	0.71000000	0.7100000	.	0.7200000	.	.
SALIP	1	0.22000000	.	0.22000000	0.2200000	.	0.2200000	.	.
SARGM	1	0.17000000	.	0.17000000	0.1700000	.	0.1700000	.	.

SPOL1	1	2.57000000	.	2.57000000	2.57000000	.	2.57000000	.	.	.	.
SPOL2	1	2.83000000	.	2.83000000	2.83000000	.	2.83000000	.	.	.	.
SNELUT	1	2.57000000	.	2.57000000	2.57000000	.	2.57000000	.	.	.	.
TSS	4	175.35000000	61.35735032	76.00000000	252.00000000	40.87867016	541.40000000	6619.02333	60.109	.	.
TDS	4	426.50000000	454.43187975	110.00000000	1097.00000000	227.21597352	1714.00000000	206508.33333	168.052	.	.
COND	4	405.00000000	471.98163306	100.00000000	1100.00000000	235.99081903	1620.00000000	222766.66667	116.539	.	.
PH	4	7.25250000	0.71341316	6.25000000	7.70000000	0.35705658	29.05000000	0.51376	9.823	.	.
TURB	4	47.25000000	5.50000000	39.00000000	50.00000000	2.75000000	182.00000000	20.45000	11.640	.	.
TOD	2	6.50000000	0.70710678	6.00000000	7.00000000	0.50000000	17.00000000	0.50000	10.579	.	.
TALIP	1	0.60000000	.	0.60000000	0.60000000	.	0.60000000	.	.	.	.
TARM	1	0.53000000	.	0.53000000	0.53000000	.	0.53000000	.	.	.	.
TPOL1	1	3.22000000	.	3.22000000	3.22000000	.	3.22000000	.	.	.	.
TPOL2	1	3.72500000	.	3.72500000	3.72500000	.	3.72500000	.	.	.	.
TPOL12	1	6.94500000	.	6.94500000	6.94500000	.	6.94500000	.	.	.	.
TNELUT	1	3.29000000	.	3.29000000	3.29000000	.	3.29000000	.	.	.	.
SHYDRO	1	0.39000000	.	0.39000000	0.39000000	.	0.39000000	.	.	.	.
PHYDRO	1	0.74000000	.	0.74000000	0.74000000	.	0.74000000	.	.	.	.
THYDRO	1	1.35000000	.	1.35000000	1.35000000	.	1.35000000	.	.	.	.
PHYDRO	1	0.11971137	.	0.11971137	0.11971137	.	0.11971137	.	.	.	.
FNELUT	1	0.25612561	.	0.25612561	0.25612561	.	0.25612561	.	.	.	.
FALIP	1	0.07200720	.	0.07200720	0.07200720	.	0.07200720	.	.	.	.
FAROM	1	0.04770477	.	0.04770477	0.04770477	.	0.04770477	.	.	.	.
TPOL	1	10.27500000	.	10.27500000	10.27500000	.	10.27500000	.	.	.	.
PPOL	1	0.92124212	.	0.92124212	0.92124212	.	0.92124212	.	.	.	.
TOCRS	2	5.30953169	0.68013821	4.68750000	5.3722134	0.62223169	10.8197074	0.77464	16.576	.	.
TOCRP	2	4.02312139	0.03269858	4.00000000	4.0462418	0.03101039	5.4462415	0.00167	0.617	.	.
TOCR	2	2.26188583	0.17461440	2.1552733	2.4054937	0.17781245	4.4657717	0.07055	7.661	.	.
PRATIO	1	5.10000000	.	5.10000000	5.10000000	.	5.10000000	.	.	.	.
SRATIO	1	5.90000000	.	5.90000000	5.90000000	.	5.90000000	.	.	.	.
TRATIO	1	5.66957676	.	5.66957676	5.66957676	.	5.66957676	.	.	.	.
ISAG							10402 FRIDAY, SEPTEMBER 27, 1985	6			
VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	S.E.M.	VARIANCE	S.V.		

STATION=ELMHURST

RESID	17	58.00000000	0.00000000	58.00000000	58.00000000	0.00000000	986.000000	0.00000	0.000	.	.
COMM	17	34.00000000	0.00000000	34.00000000	34.00000000	0.00000000	573.000000	0.00000	0.000	.	.
UNDEV	17	8.00000000	0.00000000	8.00000000	8.00000000	0.00000000	176.000000	0.00000	0.000	.	.
ROADS	17	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000	0.000	.	.
AREA	0	.	.	.	.	.	.	.	.	.	.
PRCOMM	17	92.00000000	0.00000000	92.00000000	92.00000000	0.00000000	1564.000000	0.00000	0.000	.	.
TYPE	8	1.75000000	1.02519824	0.60000000	2.00000000	0.3656253	14.000000	1.07143	53.148	.	.
OIL_SOL	8	4.32375000	2.90419911	1.51000000	10.11000000	1.62677584	34.550000	8.41420	67.158	.	.
OIL_PART	8	7.07575000	5.41133070	1.03000000	15.77000000	1.31721193	56.450000	29.23504	75.445	.	.
DILT	8	11.39125000	7.61839559	2.54000000	25.12000000	2.69247919	51.130000	58.05264	60.379	.	.
PALIP	4	5.57250000	5.23377474	2.75000000	12.42000000	2.612e-073	22.290000	27.40376	92.450	.	.
FAROM	4	0.57500000	0.33730852	0.73000000	0.62000000	0.11465470	2.500000	0.05443	49.576	.	.
PPOL1	3	0.76000000	0.17435556	0.35000000	0.85000000	0.106e-046	2.150000	0.03040	22.442	.	.
PPOL2	3	0.12000000	0.11532563	0.00000000	0.12000000	0.06552238	1.7e-04306	0.01531	56.105	.	.
FNELUT	4	0.65750000	0.25289765	0.36000000	0.93000000	0.12e-04322	2.570000	0.03595	77.353	.	.
SLIP	4	1.21758000	1.11215631	0.15000000	2.51000000	0.55e-0716	4.670000	1.17e-039	91.743	.	.
SRDM	4	0.28250000	0.16680627	0.15000000	0.52000000	0.15240414	1.171000	0.07281	53.147	.	.
SPOL1	3	1.47333333	0.67556750	0.75000000	1.47000000	0.35005698	4.450000	0.47e-047	45.241	.	.
SPOL2	3	0.02600e-067	0.02114530	0.00000000	0.02000000	0.135e-0321	1.11e-0320	0.01102	57.57	.	.
ENELUT	4	0.37000000	0.09201449	0.50000000	0.50000000	0.44600725	1.460000	0.78447	24.158	.	.
TSS	6	56.20000000	72.88610153	4.10000000	201.66000000	70.1837464	77.201100	1439.158	171.47	.	.
TDS	4	254.50000000	149.31062816	175.00000000	370.00000000	74.85515093	175.10000000	12227.66667	31.7	.	.
COND	5	755.00000000	521.97626014	50.50000000	906.00000000	171.4477427	312.00000000	1.057e-06070	91.556	.	.

FH	6	7.12500000	0.58630197	6.00000000	7.60000000	0.23935578	42.7500000	0.04375	8.228
TURB	6	25.91666667	15.94495741	12.50000000	50.00000000	6.50950160	155.5000000	254.24167	61.514
TDC	3	9.00000000	4.53257569	4.00000000	13.00000000	2.64575131	27.0000000	21.00000	50.918
TALIP	4	6.75000000	6.12084961	3.15000000	15.93000000	3.06042481	27.1600000	37.46460	90.145
TARM	4	0.85750000	0.24143667	0.58000000	1.11000000	0.12071874	3.4000000	0.05829	28.156
TFOL1	1	1.55000000	.	1.57000000	1.57000000	.	1.5700000	.	.
TFOL2	1	0.28000000	.	0.28000000	0.28000000	.	0.2800000	.	.
TFOL12	3	2.34666667	0.41525093	1.87000000	2.62000000	0.23974524	7.0400000	0.17243	17.575
TNELUT	4	1.03750000	0.28063915	0.68000000	1.29000000	0.14031958	4.1500000	0.07676	27.050
SHYDRO	4	1.50000000	1.28410409	0.46000000	2.76000000	0.60205205	6.0000000	1.44767	80.274
FHYDRO	4	6.14750000	5.07516737	3.25000000	13.75000000	2.53760868	24.5500000	25.76169	82.584
THYDRO	4	7.64750000	5.93769174	4.26000000	16.51000000	2.96874587	35.5900000	35.25856	77.645
FHYDRO	4	0.693926229	0.03999130	0.55726736	0.55463913	0.01959765	2.4707432	0.00160	6.564
FNELUT	4	0.10557371	0.05054139	0.05114988	0.15994793	0.02527069	0.4222956	0.00255	47.573
FALIP	4	0.51201778	0.06359458	0.44807366	0.63164155	0.04179729	2.0480711	0.00689	16.326
FARM	4	0.09724451	0.05599286	0.02299762	0.15737474	0.02798643	0.389780	0.00314	57.579
TFOL	3	1.38000000	0.52458598	2.82000000	5.86000000	0.30287511	9.9000000	0.27520	15.557
FFOL	3	0.42106918	0.07296119	0.38017897	0.50195059	0.04212416	1.1672575	0.00532	17.517
TOCRS	3	2.646632650	0.94587639	2.01550388	3.67392299	0.54610199	9.5404795	0.87468	32.226
TOCRP	3	2.17757356	1.60656137	0.69259457	7.65744515	0.37772486	6.5330357	2.55200	75.788
TOCR	3	1.13021906	0.54976954	0.51546392	1.57465315	0.31742114	3.7936572	0.30027	42.645
FRATIO	12	2.14165667	1.00856163	1.10000000	3.70000000	0.55114672	25.7000000	1.01720	47.092
SRATIO	12	3.15837333	1.90332643	0.70000000	7.60000000	0.54744701	37.8000000	3.62155	60.184
TRATIO	5	2.28042772	0.73032440	1.43857718	2.55520199	0.32561100	11.4621755	0.53337	21.116

19AS 1642 FRIDAY, SEPTEMBER 27, 1985 7

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
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STATION=GLEN ECHO									
RESID	5	51.00000000	0.00000000	51.00000000	51.00000000	0.00000000	255.0000000	0.000000	0.000
CCMM	5	14.00000000	0.00000000	14.00000000	14.00000000	0.00000000	70.0000000	0.000000	0.000
UNDEV	5	25.00000000	0.00000000	25.00000000	25.00000000	0.00000000	175.0000000	0.000000	0.000
ROADS	5	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	.
AREA	0	.	.	.	.	.	.	.	.
PPCCMM	5	65.00000000	0.00000000	65.00000000	65.00000000	0.00000000	325.0000000	0.000000	0.000
TYPE	5	1.20000000	1.09544512	0.00000000	3.00000000	0.48989775	6.6000000	1.5000000	91.237
OIL_SOL	5	2.67200000	3.13663355	0.70000000	8.20000000	1.46374517	15.3600000	9.353470	117.359
OIL_PART	5	4.08200000	4.33237464	0.97000000	11.00000000	1.93745584	20.4100000	15.767470	106.134
OIL_T	5	6.75200000	6.19986032	1.67000000	13.75000000	2.77221164	33.7600000	38.25570	71.806
FALIP	0	.	.	.	.	.	.	.	.
FARM	0	.	.	.	.	.	.	.	.
FPOL1	0	.	.	.	.	.	.	.	.
FPOL2	0	.	.	.	.	.	.	.	.
FNELUT	0	.	.	.	.	.	.	.	.
BALIP	0	.	.	.	.	.	.	.	.
EARM	0	.	.	.	.	.	.	.	.
SPOL1	0	.	.	.	.	.	.	.	.
SPOL2	0	.	.	.	.	.	.	.	.
SNELUT	0	.	.	.	.	.	.	.	.
TDS	5	46.56300000	51.33751677	1.14000000	153.00000000	22.73375049	152.8400000	2835.521120	110.142
TDS	4	205.75000000	87.12559661	127.00000000	530.00000000	47.53157340	622.0000000	7530.916587	42.740
CCND	5	229.00000000	147.67476578	30.00000000	460.00000000	65.11757270	1145.0000000	21855.000000	54.556
SH	5	7.55000000	0.53160372	5.90000000	8.20000000	0.21748634	36.5000000	0.132000	7.150
TURB	5	15.48000000	13.83584238	3.00000000	34.00000000	0.18745737	77.0000000	191.425100	89.942
TDC	2	6.00000000	1.41421356	5.00000000	7.00000000	1.00000000	12.0000000	2.000000	17.570
TALIP	0	.	.	.	.	.	.	.	.
TARM	0	.	.	.	.	.	.	.	.
TPOL1	0	.	.	.	.	.	.	.	.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD. ERROR OF MEAN	SUM	VARIANCE	C.V.
TPOL2	0	.	.	.	.	.	.	.	.
TFOL12	0	.	.	.	.	.	.	.	.
TNELUT	0	.	.	.	.	.	.	.	.
SHYDRO	0	.	.	.	.	.	.	.	.
FHYDRO	0	.	.	.	.	.	.	.	.
THYDRO	0	.	.	.	.	.	.	.	.
FHYDRO	0	.	.	.	.	.	.	.	.
FNELUT	0	.	.	.	.	.	.	.	.
FALIP	0	.	.	.	.	.	.	.	.
FAFOM	0	.	.	.	.	.	.	.	.
TPOL	0	.	.	.	.	.	.	.	.
FFPOL	0	.	.	.	.	.	.	.	.
TOCRS	2	4.56084875	3.16114569	2.32556140	6.79611650	2.23526755	9.1216573	9.572842	67.310
TOCRP	2	2.40112577	2.75236514	0.45454545	4.34762609	1.74564032	4.8022715	7.523817	114.650
TOCR	2	1.51587164	1.66604245	0.38022614	2.65151515	1.13564331	3.0317433	2.575372	103.948
PRATIO	0	.	.	.	.	.	.	.	.
SRATIO	0	.	.	.	.	.	.	.	.
TRATIO	0	.	.	.	.	.	.	.	.
ISAG							16462	FRIDAY, SEPTEMBER 27, 1985	8

VARIABLE N MEAN STANDARD MINIMUM MAXIMUM STD. ERROR SUM VARIANCE S.D.

STATION=GUADALUPE

RESID	5	22.00000000	0.00000000	22.00000000	22.00000000	0.00000000	110.0000000	0.00000000	0.0000
COMM	5	4.00000000	0.00000000	4.00000000	4.00000000	0.00000000	20.0000000	0.00000000	0.0000
UNGEV	5	74.00000000	0.00000000	74.00000000	74.00000000	0.00000000	370.0000000	0.00000000	0.0000
ROADS	5	7.70000000	0.00000000	7.70000000	7.70000000	0.00000000	28.5000000	0.00000000	0.0000
AREA	0	-	-	-	-	-	-	-	-
PRCOMM	5	26.00000000	0.00000000	26.00000000	26.00000000	0.00000000	130.0000000	0.00000000	0.0000
TYPE	5	1.66000000	1.14317543	0.00000000	3.00000000	0.53390175	8.00000000	1.77100000	71.201
OIL_SOL	5	4.08600000	4.32061685	0.75000000	10.54000000	1.57227260	20.45000000	16.587700	105.742
OIL_PART	5	3.30300000	2.50586206	0.87500000	7.21000000	1.12188453	16.5150100	8.277445	75.857
SIL_T	5	7.33600000	6.58605876	1.62000000	17.75000000	0.74537502	75.5400000	42.376170	59.135
FALIP	1	2.41000000	-	2.41000000	2.41000000	-	2.41000000	-	-
FARDM	1	1.09000000	-	1.09000000	1.09000000	-	1.09000000	-	-
FPCL1	1	2.02000000	-	2.02000000	2.02000000	-	2.12000000	-	-
FPDL2	1	1.68000000	-	1.68000000	1.68000000	-	1.68000000	-	-
PNELUT	1	0.00000000	-	0.00000000	0.00000000	-	0.00000000	-	-
SALIP	1	1.03000000	-	1.03000000	1.03000000	-	1.03000000	-	-
SADM	1	2.44000000	-	2.44000000	2.44000000	-	2.44000000	-	-
SPDL1	1	3.19000000	-	3.19000000	3.19000000	-	3.19000000	-	-
SPDL2	1	2.44000000	-	2.44000000	2.44000000	-	2.44000000	-	-
SKELUT	1	1.44000000	-	1.44000000	1.44000000	-	1.44000000	-	-
TSS	5	68.14000000	60.92817800	19.90000000	156.00000000	27.14735146	340.7000000	3712.225420	69.415
TDS	5	229.00000000	140.64136793	114.00000000	472.00000000	62.83674077	1145.0000000	16780.000000	61.415
COND	5	212.00000000	167.65752619	115.00000000	559.00000000	84.81745103	1060.0000000	35970.000000	63.451
PH	5	6.58800000	0.53171421	8.30000000	7.56000000	1.23773532	74.5400000	0.132720	7.638
TURB	5	38.50000000	14.42220510	12.50000000	50.00000000	5.44730520	192.5000000	208.000000	37.492
TSC	2	6.00000000	0.00000000	6.00000000	6.00000000	0.00000000	12.0000000	0.00000000	1.000
TALIP	1	3.44000000	-	3.44000000	3.44000000	-	3.44000000	-	-
TPADM	1	3.55000000	-	3.55000000	3.55000000	-	3.55000000	-	-
TFGL1	1	5.21000000	-	5.21000000	5.21000000	-	5.21000000	-	-
TFGL2	1	4.12000000	-	4.12000000	4.12000000	-	4.12000000	-	-
TFDL12	1	9.35000000	-	9.35000000	9.35000000	-	9.35000000	-	-
TNELUT	1	1.44000000	-	1.44000000	1.44000000	-	1.44000000	-	-
SHYDRO	1	3.47000000	-	3.47000000	3.47000000	-	3.47000000	-	-
PHYDRO	1	2.50000000	-	3.50000000	3.50000000	-	3.50000000	-	-
THYDRO	1	6.57000000	-	6.57000000	6.57000000	-	6.57000000	-	-

FHYDRO	1	0.39267606	.	0.39267606	0.39267606	.	0.3926761	.	.	.	.
FNELUT	1	0.08112676	.	0.08112676	0.08112676	.	0.0811268	.	.	.	.
FALIP	1	0.19380282	.	0.19380282	0.19380232	.	0.1938028	.	.	.	.
FAROM	1	0.19887324	.	0.19887324	0.19887324	.	0.1988732	.	.	.	.
TPOL	1	10.77000000	.	10.77000000	10.77000000	.	10.7700000	.	.	.	.
FPOL	1	0.60676056	.	0.60676056	0.60676056	.	0.6067606	.	.	.	.
TOCRS	2	4.70465971	0.59573099	4.28571429	5.12520513	0.42124542	9.4139194	0.354895	12.656	.	.
TOCRP	2	2.89865780	1.91631169	1.54241645	4.25531915	1.35545135	5.7977356	3.679921	66.175	.	.
TOCR	2	1.72989345	0.84242290	1.13421550	2.72558140	0.59556295	3.4597969	0.709676	48.678	.	.
FRATIO	1	9.40000000	.	9.40000000	9.40000000	.	9.4000000	.	.	.	.
SRATIO	1	9.90000000	.	9.90000000	9.90000000	.	9.9000000	.	.	.	.
TRATIO	1	9.69690141	.	9.69690141	9.69690141	.	9.6969014	.	.	.	.
ISAS										16:02 FRIDAY, SEPTEMBER 27, 1985	9
VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SLM	VARIANCE	C.V.		
STATION=MATERDERO											
RESID	7	5.00000000	0.00000000	5.00000000	5.00000000	0.00000000	25.000000	0.00000	0.0000	.	.
CDMM	7	2.00000000	0.00000000	2.00000000	2.00000000	0.00000000	14.000000	0.00000	0.0000	.	.
UNDEV	7	93.00000000	0.00000000	93.00000000	93.00000000	0.00000000	651.090000	0.00000	0.0000	.	.
ROADS	7	1.20000000	0.00000000	1.20000000	1.20000000	0.00000000	8.400000	0.00000	0.0000	.	.
AREA	0										
FRDCMM	7	7.00000000	0.00000000	7.00000000	7.00000000	0.00000000	45.000000	0.00000	0.0000	.	.
TYPE	7	2.14285714	1.21495579	0.00000000	3.00000000	0.43922146	15.000000	1.47619	56.899	.	.
OIL_SOL	7	1.183557143	1.03563604	0.50000000	3.3400000	0.37181166	8.320000	1.07481	87.217	.	.
OIL_PART	7	1.11071429	1.40177991	0.23000000	4.2200000	0.51582700	7.775000	1.96479	128.205	.	.
OIL_T	7	2.29725571	2.37124867	0.93000000	7.5600000	0.67624775	16.075000	5.52182	103.130	.	.
PALIP	4	0.76125000	0.18140080	0.19000000	0.5750000	0.09070040	1.4450000	0.67291	50.215	.	.
PAROM	4	0.60250000	0.65359250	0.19000000	1.5900000	0.37154825	2.4100000	0.43769	110.057	.	.
FPOL1	4	0.25750000	0.13865425	0.09000000	0.4200000	0.06932712	1.9300000	0.01923	53.845	.	.
FPOL2	4	0.10175000	0.14015151	0.00000000	0.2700000	0.07055757	0.4700000	0.01963	137.705	.	.
FNELUT	4	0.34500000	0.69000000	0.00000000	1.3800000	0.34500000	1.3800000	0.47610	200.000	.	.
SALIP	4	0.21250000	0.15063753	0.09000000	0.4100000	0.07531877	0.2500000	0.02269	70.988	.	.
SAROM	4	0.34500000	0.27380041	0.15000000	0.7500000	0.13860021	1.3800000	0.07497	79.562	.	.
SPOL1	4	0.60750000	0.41411552	0.27000000	1.1300000	0.27015776	2.4700000	0.17149	68.167	.	.
SPOL2	4	0.256660000	0.48725711	0.00000000	0.9500000	0.24761555	1.0400000	0.25740	187.359	.	.
SNELUT	4	0.17500000	0.21501936	0.00000000	0.4400000	0.10750959	0.7000000	0.04623	122.868	.	.
TSS	6	29.45333333	43.74988358	1.62000000	117.000000	17.74246484	176.7200000	1931.58127	149.219	.	.
TDS	6	1251.00000000	961.17554643	490.00000000	3114.0000000	772.37842657	7505.0000000	92355.20000	76.833	.	.
COND	6	1050.87333333	263.43741329	435.00000000	2750.0000000	752.49284790	6305.0000000	745524.15667	82.167	.	.
PH	6	7.61666667	0.40702170	7.10000000	8.0000000	0.1e+16591	45.7000000	0.16597	5.344	.	.
TURB	6	22.16666667	18.03792701	1.00000000	50.0000000	7.7475123	132.0000000	325.76667	81.374	.	.
TDC	3	11.33333333	2.03166600	9.00000000	13.0000000	1.20165043	34.0000000	4.33333	18.368	.	.
TALIP	5	0.56100000	0.28408625	0.28000000	0.9450000	0.12704724	2.8050000	0.26071	50.639	.	.
TAROM	5	0.80400000	0.87093428	0.27000000	2.3400000	0.33544454	4.0100000	0.75353	106.725	.	.
TPOL1	2	0.74000000	0.20811183	0.31000000	1.1700000	0.43000000	1.4800000	0.56590	82.177	.	.
TPOL2	2	0.57350000	0.59534395	0.07000000	1.2370000	0.61250000	1.3570000	0.74054	126.871	.	.
TPOL12	4	1.12675000	0.90676104	0.50000000	2.4570000	0.45373862	4.7470000	0.62222	76.407	.	.
TNELUT	5	0.41400000	0.77421860	-0.01000000	1.8200000	0.33518446	2.0700000	0.65078	191.840	.	.
SHYDRO	4	0.55750000	0.40335055	0.71600000	1.1600000	0.20167523	2.2300000	0.16269	72.350	.	.
PHYDRO	4	0.96375000	0.75697384	0.33000000	2.1250000	0.34446872	3.6550000	0.62242	81.661	.	.
THYDRO	5	1.36500000	1.08591601	0.65000000	3.2950000	0.43675526	5.8250000	1.16572	79.774	.	.
FHYDRO	5	0.54291555	0.16573951	0.27615734	0.6566047	0.37575513	2.7145778	0.02669	31.201	.	.
FNELUT	5	0.06866797	0.10827376	-0.006226889	0.2407407	0.04842755	0.3434798	0.01172	157.638	.	.
FALIP	5	0.27074592	0.16373467	0.12017167	0.4537233	0.07222477	1.357296	0.02891	60.475	.	.
FAROM	5	0.27216764	0.10526553	0.17556567	0.4385582	0.04712975	1.5608482	0.01111	38.720	.	.
TPOL	4	1.70675000	1.77069165	0.50000000	4.2770000	0.65534582	6.6270000	3.13525	107.746	.	.
FPOL	4	0.46863574	0.15463581	0.33139535	0.6551731	0.07741906	1.8747950	0.02397	73.636	.	.

TOCRS	3	16.77171575	4.00531966	12.16216216	19.4029851	2.31247238	50.3151472	16.04259	20.351
TOCRP	3	22.04651117	14.83621604	12.38095238	39.1304748	8.56569333	66.1455335	220.11731	67.129
TOCR	3	8.35165933	0.86775075	7.55613953	9.2787505	0.50099590	25.0556681	0.75295	10.350
FRATIO	6	25.71666667	3.05314046	22.00000000	31.3000000	1.24643937	154.3000000	9.33167	11.372
SRATIO	6	25.61666667	10.40969100	13.90000000	44.0000000	4.24973555	153.7000000	106.36167	40.636
TRATIO	6	25.36029062	6.61533752	18.42142857	36.8671233	2.70070024	152.1612037	43.76267	26.086
ISAS								16:02 FRIDAY, SEPTEMBER 27, 1985	10

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
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STATION=NAPA									
RESID	5	10.00000000	0.00000000	10.00000000	10.0000000	0.0000000	50.0000000	0.0000	0.000
COMM	5	3.00000000	0.00000000	3.00000000	3.0000000	0.0000000	15.0000000	0.0000	0.000
UNDEV	5	87.00000000	0.00000000	87.00000000	87.0000000	0.0000000	435.0000000	0.0000	0.000
RCAOS	5	0.00000000	0.00000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000	.
AREA	0	.	.	.	.	.	.	.	.
FRCOMM	5	13.00000000	0.00000000	13.00000000	13.0000000	0.0000000	65.0000000	0.0000	0.000
TYPE	5	1.20000000	1.09544512	0.00000000	3.0000000	0.4398979	6.0000000	1.2000	91.227
OIL_SOL	5	1.24400000	1.54166468	0.55000000	4.0900000	0.8294534	6.7200000	2.3757	114.707
OIL_PART	5	1.16200000	1.76351034	0.15900000	3.5800000	0.6277619	5.8100000	1.8572	117.742
OIL_T	5	2.52500000	2.68489688	0.70000000	7.5500000	1.2901651	12.6500000	6.1120	114.206
PALIP	0	.	.	.	.	.	.	.	.
TAROM	0	.	.	.	.	.	.	.	.
TPOL1	0	.	.	.	.	.	.	.	.
TPOL2	0	.	.	.	.	.	.	.	.
PNELUT	0	.	.	.	.	.	.	.	.
SALIP	0	.	.	.	.	.	.	.	.
SARCH	0	.	.	.	.	.	.	.	.
SPOL1	0	.	.	.	.	.	.	.	.
SPOL2	0	.	.	.	.	.	.	.	.
SHELUT	0	.	.	.	.	.	.	.	.
TSS	5	1651.39000000	2261.81746391	4.35000000	4630.0000000	1011.5155293	8253.9500000	5115318.3745	116.954
TDS	5	237.40000000	97.25636226	108.00000000	377.0000000	42.4442875	1127.0000000	9458.000	40.567
CDW	5	151.00000000	128.37445259	45.00000000	350.0000000	57.4106804	755.0000000	18450.000	35.116
PH	5	6.98000000	0.24897799	6.60000000	7.3000000	0.1113553	74.9000000	0.1620	3.367
TURB	5	28.40000000	21.62640127	5.00000000	50.0000000	9.5784535	142.0000000	470.1000	76.061
TOC	2	10.00000000	1.41421356	9.00000000	11.8000000	1.0000000	20.6000000	2.0000	14.142
TALIP	0	.	.	.	.	.	.	.	.
TAROM	0	.	.	.	.	.	.	.	.
TPOL1	0	.	.	.	.	.	.	.	.
TPOL2	0	.	.	.	.	.	.	.	.
TPOL12	0	.	.	.	.	.	.	.	.
TIELUT	0	.	.	.	.	.	.	.	.
SHYDRO	0	.	.	.	.	.	.	.	.
PHYDRO	0	.	.	.	.	.	.	.	.
THYDRO	0	.	.	.	.	.	.	.	.
PRHYDRO	0	.	.	.	.	.	.	.	.
FNELUT	0	.	.	.	.	.	.	.	.
PALIP	0	.	.	.	.	.	.	.	.
TAROM	0	.	.	.	.	.	.	.	.
TPOL	0	.	.	.	.	.	.	.	.
FPOL	0	.	.	.	.	.	.	.	.
TOCRS	2	18.00324575	2.01875825	15.3626736	19.6433871	1.6296104	15.0064475	5.2730	10.351
TOCRP	2	37.14285714	32.32466143	14.16371429	56.0000000	22.6571429	74.2357142	1744.688	37.124
TOCR	2	10.5676977	3.247312133	8.2716769	11.3571429	2.2373331	21.1273175	14.5176	71.010
FRATIO	0	.	.	.	.	.	.	.	.
SRATIO	0	.	.	.	.	.	.	.	.
TRATIO	0	.	.	.	.	.	.	.	.

16AS

16:02 FRIDAY, SEPTEMBER 27, 1965 11

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
STATION=PINE-GALLINDA									
FE3ID	4	23.00000000	0.00000000	23.00000000	23.00000000	0.00000000	92.00000000	0.000000	0.000
COMM	4	5.00000000	0.00000000	5.00000000	5.00000000	0.00000000	20.00000000	0.000000	0.000
UNDEV	4	72.00000000	0.00000000	72.00000000	72.00000000	0.00000000	288.00000000	0.000000	0.000
ROADS	4	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.000
AREA	0	.	.	.	.	.	.	.	.
PROCOMM	4	28.00000000	0.00000000	28.00000000	28.00000000	0.00000000	112.00000000	0.000000	0.000
TYPE	4	1.25000000	0.50000000	1.00000000	2.00000000	0.25000000	5.00000000	0.250000	40.000
CIL_SOL	4	2.20000000	1.31227538	1.04000000	3.55000000	0.65513769	8.50000000	1.722057	59.649
CIL_FART	4	1.73750000	1.27185288	0.54000000	3.55000000	0.65592544	8.75000000	1.617525	73.201
CIL_T	4	3.93750000	2.35953756	1.65000000	7.05000000	1.15476658	15.75000000	5.709582	60.637
FALIP	0	.	.	.	.	.	.	.	.
PARM	0	.	.	.	.	.	.	.	.
TPOL1	0	.	.	.	.	.	.	.	.
TPOL2	0	.	.	.	.	.	.	.	.
PNELUT	0	.	.	.	.	.	.	.	.
BALIP	0	.	.	.	.	.	.	.	.
SAREM	0	.	.	.	.	.	.	.	.
SPOL1	0	.	.	.	.	.	.	.	.
SPOL2	0	.	.	.	.	.	.	.	.
SNELUT	0	.	.	.	.	.	.	.	.
TSS	4	93.32000000	114.96161794	6.78000000	250.00000000	57.43050697	373.25000000	13216.177100	125.181
TDS	3	352.33333333	245.21283273	145.00000000	623.00000000	141.57259458	1057.00000000	60129.333333	62.537
COND	4	372.50000000	275.51466791	175.00000000	750.00000000	127.75731495	1490.00000000	73918.333333	73.564
FH	4	7.35750000	0.57953151	5.55000000	7.70000000	0.23966576	27.35000000	0.3355625	7.855
TURB	4	28.00000000	25.52123279	3.00000000	50.00000000	12.7-081650	112.00000000	651.333333	81.147
TOC	2	5.00000000	1.41421355	4.00000000	6.00000000	1.00000000	10.00000000	2.000000	28.284
TALIP	0	.	.	.	.	.	.	.	.
TARM	0	.	.	.	.	.	.	.	.
TPOL1	0	.	.	.	.	.	.	.	.
TPOL2	0	.	.	.	.	.	.	.	.
TPOL12	0	.	.	.	.	.	.	.	.
TNELUT	0	.	.	.	.	.	.	.	.
SHYDRO	0	.	.	.	.	.	.	.	.
PHYDRO	0	.	.	.	.	.	.	.	.
THYDRO	0	.	.	.	.	.	.	.	.
FHYDRO	0	.	.	.	.	.	.	.	.
FNELUT	0	.	.	.	.	.	.	.	.
FALIP	0	.	.	.	.	.	.	.	.
FARM	0	.	.	.	.	.	.	.	.
TPOL	0	.	.	.	.	.	.	.	.
FPOL	0	.	.	.	.	.	.	.	.
TOCRS	2	4.66341719	1.53102365	0.60760060	5.76723077	1.16261553	5.5725344	2.744571	32.675
TOCRF	2	5.62676063	2.51216654	0.64615035	7.40740741	1.73062678	11.2575613	5.341563	44.754
TOCR	2	1.35596737	0.08241338	0.33765231	2.42424242	0.05827506	4.7315747	0.006752	3.453
FRATIO	0	.	.	.	.	.	.	.	.
SRATIO	0	.	.	.	.	.	.	.	.
TRATIO	0	.	.	.	.	.	.	.	.

16AS

16:02 FRIDAY, SEPTEMBER 27, 1965 12

D	ERROR	SUM	VARIANCE	C.V.	DEVIATION	VALUE	VALUE	STD. OF MEAN	
STATION=RICHMOND -----									
RESID	5	73.00000000	0.00000000	73.00000000	73.00000000	0.00000000	365.0000000	0.000000	0.000
COMM	5	22.00000000	0.00000000	22.00000000	22.00000000	0.00000000	110.0000000	0.000000	0.000
UNDEV	5	5.00000000	0.00000000	5.00000000	5.00000000	0.00000000	25.0000000	0.000000	0.000
ROADS	5	0.20000000	0.00000000	0.20000000	0.20000000	0.00000000	1.0000000	0.000000	0.000
AREA	0								
FRCOMM	5	95.00000000	0.00000000	95.00000000	95.00000000	0.00000000	475.0000000	0.000000	0.000
TYPE	5	1.20000000	1.07544512	0.00000000	3.00000000	0.45889795	6.0000000	1.200000	51.137
OIL_SOL	5	3.40600000	3.19075696	0.75000000	8.42000000	1.42674589	17.0300000	10.130730	93.560
OIL_PART	5	3.09040000	2.21672750	0.62200000	6.15000000	0.99135067	15.4520000	4.913581	71.719
OIL_T	5	6.42200000	3.85995970	1.71000000	10.45000000	1.72577924	32.4100000	14.531570	59.553
FALIP	0	.	.	.	.	.	.	.	.
FAROM	0	.	.	.	.	.	.	.	.
FPOL1	0	.	.	.	.	.	.	.	.
FPOL2	0	.	.	.	.	.	.	.	.
FNELUT	0	.	.	.	.	.	.	.	.
SALIP	0	.	.	.	.	.	.	.	.
SAROM	0	.	.	.	.	.	.	.	.
SPOL1	0	.	.	.	.	.	.	.	.
SPOL2	0	.	.	.	.	.	.	.	.
ENELUT	0	.	.	.	.	.	.	.	.
TSS	5	25.00000000	29.55308783	1.50000000	75.10000000	13.11e54265	145.0000000	577.5250000	182.372
TSS	5	203.60000000	169.38358534	61.00000000	454.00000000	75.75064356	1048.0000000	2859.5000000	50.513
OCAD	5	191.60000000	174.24924677	48.00000000	490.00000000	77.95863214	953.0000000	30761.600000	50.513
FH	5	4.65200000	0.59170379	6.20000000	7.50000000	0.15462048	74.4100000	6.351120	6.5578
TURB	5	22.90000000	20.69541012	1.50000000	48.00000000	9.33526877	114.5000000	423.7000000	59.373
TEC	2	2.00000000	4.24264069	5.00000000	11.30000000	3.00000000	16.0000000	18.000000	57.353
TALIP	0	.	.	.	.	.	.	.	.
TAROM	0	.	.	.	.	.	.	.	.
TPOL1	0	.	.	.	.	.	.	.	.
TPOL2	0	.	.	.	.	.	.	.	.
TPOL12	0	.	.	.	.	.	.	.	.
TNELUT	0	.	.	.	.	.	.	.	.
SHYDRO	0	.	.	.	.	.	.	.	.
PHYDRO	0	.	.	.	.	.	.	.	.
THYDRO	0	.	.	.	.	.	.	.	.
PHYDRO	0	.	.	.	.	.	.	.	.
FNELUT	0	.	.	.	.	.	.	.	.
FALIP	0	.	.	.	.	.	.	.	.
FAROM	0	.	.	.	.	.	.	.	.
TFOL	0	.	.	.	.	.	.	.	.
FPOL	0	.	.	.	.	.	.	.	.
TCRAS	2	7.09523639	6.17027946	2.77224444	11.45833333	4.75054645	14.1505773	18.172749	68.563
TCRCP	2	3.00653537	3.12065324	0.60000000	5.21337014	2.21e53507	6.0132741	9.773472	107.172
TCR	2	2.10057689	2.07664128	0.61851158	7.53036189	1.45212500	4.2016756	4.0132739	54.767
FRATIO	0	.	.	.	.	.	.	.	.
ERATIO	0	.	.	.	.	.	.	.	.
TRATIO	0	.	.	.	.	.	.	.	.
ISAS								16802 FRIDAY, SEPTEMBER 27, 1985	17
VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD. OF MEAN	SUM	AVERAGE	C.V.

STATION=SLEEPY HOLLOW -----

RESID	14	26.00000000	0.00000000	26.00000000	26.00000000	0.00000000	364.0000000	26.0000000	0.000
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	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
STATION=SONOMA -----									
RE310	5	2.00000000	0.00000000	2.00000000	2.00000000	0.00000000	10.0000000	0.00150	0.000
COMM	5	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.00000	.
UNDEV	5	98.00000000	0.00000000	98.00000000	98.00000000	0.00000000	490.0000000	0.00000	0.000
ROADS	5	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.00000	.
AREA	0								
FRECOMM	5	2.00000000	0.00000000	2.00000000	2.00000000	0.00000000	10.0000000	0.00000	0.000
TYPE	7	1.42857143	1.13339342	0.00000000	3.00000000	0.42857143	10.0000000	1.285714	73.373
OIL_SOL	7	1.63857143	1.74714461	0.18000000	5.33000000	0.65035359	11.4700000	3.052514	105.626
OIL_PART	7	2.03142557	1.10277572	0.79000000	3.72000000	0.4161004	14.2200000	1.216114	54.286
OIL_T	7	3.67000000	2.70564665	1.44000000	9.05000000	1.02777220	25.6900000	7.336767	73.805
PALIP	4	0.40250000	0.17442764	0.18000000	0.60000000	0.0372132	1.6100000	0.030425	43.336
FAROM	4	0.39500000	0.18292964	0.24000000	0.66000000	0.07464847	1.5900000	0.035873	47.923
FPOL1	4	0.62750000	0.34357362	0.16000000	0.91000000	0.17191931	2.5100000	0.118225	54.795
FPOL2	4	0.01500000	0.03000000	0.00000000	0.06000000	0.01500000	0.0600000	0.000900	200.000
FNELUT	4	0.09000000	0.10165300	0.01000000	0.23000000	0.05082650	0.3600000	0.010333	112.548
SALIP	4	0.16000000	0.05262653	0.10000000	0.28000000	0.04143263	0.6400000	0.006557	51.791
BAROM	4	0.19250000	0.06551681	0.15000000	0.19000000	0.03275541	0.7700000	0.004192	34.032
SPOL1	4	0.44500000	0.30356235	0.15000000	0.82000000	0.15419144	1.7200000	0.09100	69.300
SPOL2	4	0.02750000	0.05500000	0.00000000	0.11000000	0.02758000	0.1100000	0.003025	200.000
SNELUT	4	0.17625000	0.25223554	0.00000000	0.55000000	0.128111792	0.7050000	0.055622	143.113
TSS	6	192.74333333	304.99370002	3.6400000	717.0000000	124.51325053	1182.4600000	52021.297347	153.461
TDS	6	250.66666667	65.56325313	149.0000000	342.0000000	27.17473450	1534.0000000	4430.666667	26.554
COND	6	246.50000000	135.77739134	90.0000000	460.0000000	55.40685790	1479.0000000	18435.500000	55.082
PH	6	7.37500000	0.27522716	7.1000000	7.3500000	0.11275103	44.2500000	0.073750	3.732
TURB	6	32.25000000	22.77663276	1.5000000	50.0000000	5.23552139	193.5000000	518.77500	70.625
TOC	3	8.66500067	2.383949108	6.0000000	10.0000000	1.53333333	16.0000000	5.555555	26.847
TALIP	4	0.56250000	0.16879475	0.7300000	0.7100000	0.06417737	2.2500000	0.021400	34.008
TARGM	4	0.58750000	0.19500000	0.4000000	0.8100000	0.05750000	2.3500000	0.032025	33.191
TFOL1	1	0.73000000	.	0.7300000	0.7200000	.	0.7300000	.	.
TFOL2	1	0.17000000	.	0.1700000	0.1700000	.	0.1700000	.	.
TPOL12	4	1.11500000	0.41733280	0.6200000	1.7200000	0.21862240	4.4600000	0.174167	37.429
TNELUT	4	0.26625000	0.34730810	0.0200000	0.7300000	0.17754505	1.0500000	0.126623	130.444
SHYDRO	4	0.35250000	0.107151919	0.2500000	0.4500000	0.05255550	1.4100000	0.011492	30.411
PHYDRO	4	0.77950000	0.23500000	0.5300000	1.1100000	0.11750000	3.1500000	0.055225	29.467
THYDRO	4	1.15000000	0.146128739	1.0200000	1.3500000	0.07314739	4.6000000	0.021400	12.721
FHYDRO	4	0.49154279	0.12817445	0.30575512	0.523569057	0.05406722	1.5841656	0.016429	26.076
FNELUT	4	0.08451619	0.080904165	0.01035641	0.21487603	0.04452132	0.3460408	0.007918	102.726
FALIP	4	0.23357111	0.075866346	0.16417910	0.33348154	0.03793173	0.9742844	0.005755	32.480
FAROM	4	0.25797128	0.112579745	0.11015234	0.34753448	0.03515762	1.0318351	0.012832	43.568
TPOL	4	1.38125000	0.76446466	0.8400000	2.5100000	0.38223234	5.5250000	0.564466	55.346
FPOL	4	0.53109380	0.11193325	0.43076923	0.69148006	0.05596663	2.1243752	0.012529	21.076
TOCRS	3	23.18840580	9.50353409	14.49275352	33.3333333	5.46563777	89.552174	90.317180	40.984
TOCRP	3	6.01573543	1.68935556	4.76152476	7.37650774	0.97575219	18.0480663	2.853556	28.084
TOCR	3	4.52390576	0.52276651	4.16666657	5.12320513	0.30162071	17.5671717	0.273237	11.543
PRATIO	13	15.16153246	3.13063650	12.0000000	24.7000000	0.86623270	137.1000000	9.800557	20.649
SRATIO	13	14.29220769	2.59191754	9.4000000	18.1000000	0.73378047	165.2000000	6.709103	18.123
TRATIO	6	14.27975923	2.23087687	12.30346259	17.17765595	0.91074722	25.6735554	4.974735	15.623
15AS							16:02 FRIDAY, SEPTEMBER 27, 1985	14	

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
STATION=SONOMA -----									
RE310	5	2.00000000	0.00000000	2.00000000	2.00000000	0.00000000	10.0000000	0.00150	0.000
COMM	5	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.00000	.
UNDEV	5	98.00000000	0.00000000	98.00000000	98.00000000	0.00000000	490.0000000	0.00000	0.000
ROADS	5	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.00000	.
AREA	0								
FRECOMM	5	2.00000000	0.00000000	2.00000000	2.00000000	0.00000000	10.0000000	0.00000	0.000
TYPE	5	1.20000000	1.06544512	0.00000000	3.00000000	0.43536795	5.0000000	1.20000	91.287

OIL_SOL	5	0.75200000	0.30523761	0.40000000	1.09000000	0.13650641	3.7600000	0.09317	40.530
OIL_PART	5	0.79200000	0.39720272	0.36000000	1.33000000	0.17763446	3.8600000	0.15777	50.152
OIL_T	5	1.54200000	0.56446435	0.94000000	2.42000000	0.25247613	7.7100000	0.31362	78.036
PALIP	0	.	.	.	.	.	.	.	.
FARM	0	.	.	.	.	.	.	.	.
PFOL1	0	.	.	.	.	.	.	.	.
PFOL2	0	.	.	.	.	.	.	.	.
PNELUT	0	.	.	.	.	.	.	.	.
SALIP	0	.	.	.	.	.	.	.	.
SARM	0	.	.	.	.	.	.	.	.
SPOL1	0	.	.	.	.	.	.	.	.
SPOL2	0	.	.	.	.	.	.	.	.
SNELUT	0	.	.	.	.	.	.	.	.
TGS	5	348.14000000	464.16117675	1.80000000	852.00000000	207.57918874	1740.7000000	215445.59300	131.313
TGS	5	214.80000000	51.11936792	163.00000000	280.00000000	21.69132165	1074.6000000	2613.20000	23.733
COND	5	172.00000000	151.22499762	55.00000000	335.00000000	52.62560300	850.0000000	17220.00000	78.194
FH	5	7.30000000	0.74161765	6.10000000	8.00000000	0.73166249	56.5000000	1.55300	16.159
TURB	5	26.50000000	22.02652564	1.50000000	50.00000000	5.65160337	154.5000000	485.70000	51.674
TDC	2	8.00000000	0.00000000	8.00000000	8.00000000	2.70000000	15.0000000	8.00000	8.000
TALIP	0	.	.	.	.	.	.	.	.
TARM	0	.	.	.	.	.	.	.	.
TPOL1	0	.	.	.	.	.	.	.	.
TPOL2	0	.	.	.	.	.	.	.	.
TPOL12	0	.	.	.	.	.	.	.	.
TNELLUT	0	.	.	.	.	.	.	.	.
SHYDRO	0	.	.	.	.	.	.	.	.
PHYDRO	0	.	.	.	.	.	.	.	.
THYDRO	0	.	.	.	.	.	.	.	.
PHYDRO	0	.	.	.	.	.	.	.	.
PNELUT	0	.	.	.	.	.	.	.	.
PALIP	0	.	.	.	.	.	.	.	.
FARM	0	.	.	.	.	.	.	.	.
TPOL	0	.	.	.	.	.	.	.	.
PFOL	0	.	.	.	.	.	.	.	.
TCRAS	2	14.25831915	8.12420557	8.51062630	20.00000000	8.74466035	13.5106263	88.0372	52.531
TCRCP	2	9.14655364	1.75113777	7.76659027	10.51631377	1.37563275	18.19732081	5.51354	21.732
TCR	2	5.15014397	0.62822061	4.70582375	5.59440557	0.44416162	10.3002879	0.58474	12.137
PRATIO	0	.	.	.	.	.	.	.	.
GRATIO	0	.	.	.	.	.	.	.	.
TRATIO	0	.	.	.	.	.	.	.	.
1946								16:02 FRIDAY, SEPTEMBER 27, 1985	15

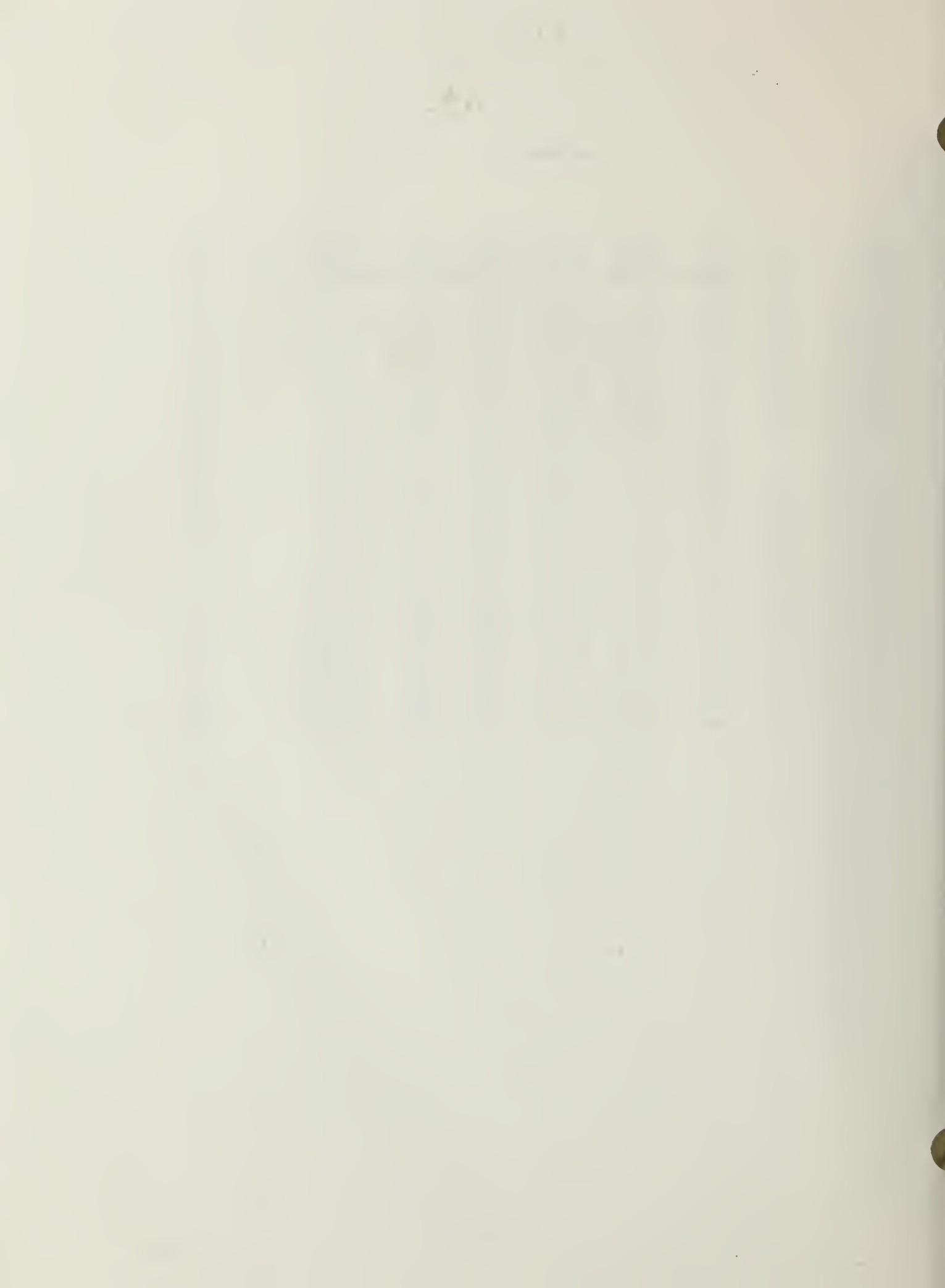
VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD. ERROR OF MEAN	BUS	PERCENTAGE	C.I.V.
STATION=TEMESCAL -----									
RESID	10	52.00000000	0.00000000	52.00000000	52.00000000	0.00000000	520.0000000	0.00000	0.000
COMM	10	13.00000000	0.00000000	13.00000000	13.00000000	0.00000000	130.0000000	0.00000	0.000
UNDEV	10	34.00000000	0.00000000	34.00000000	34.00000000	0.00000000	340.0000000	0.00000	0.000
ROADS	10	8.00000000	0.00000000	8.00000000	8.00000000	0.00000000	80.0000000	0.00000	0.000
AREA	0	.	.	.	.	.	.	.	.
PRODM	10	56.00000000	0.00000000	56.00000000	56.00000000	0.00000000	560.0000000	0.00000	0.000
TYPE	10	1.73000000	1.05974591	0.00000000	3.00000000	0.00435525	17.0000000	17.12222	52.75
OIL_SOL	10	2.69500000	1.75740707	0.94000000	7.25300000	0.54321656	26.9500000	7.18587	50.47
OIL_PART	10	12.44700000	15.55638447	1.56000000	47.73000000	3.15356566	124.4700000	355.94500	108.531
OIL_T	10	15.34800000	16.47224556	2.50000000	46.51000000	5.21378172	151.4200000	271.77417	107.722
PALIP	5	7.20833333	10.54904686	0.41000000	52.85000000	4.46382347	47.1500000	115.70167	101.174
FARM	5	0.34633333	0.71953520	0.26000000	2.16000000	0.2775045	3.6300000	0.57777	11.462
PFOL1	4	2.69250000	4.54824876	0.52000000	9.81000000	0.27441478	11.3700000	17.63103	112.16

PFOL2	4	0.06250000	0.10012492	0.00000000	0.21000000	0.05006246	0.25000000	0.010025	160.200
FNLUT	6	0.53166667	1.20075671	-0.01000000	2.92000000	0.49020687	3.19000000	1.441817	225.248
SALIP	6	0.55916667	0.37421335	0.21500000	1.21000000	0.16093693	3.35500000	0.155404	70.500
SARM	6	0.26750000	0.11660852	0.15000000	0.42000000	0.04760515	1.60500000	0.017558	43.592
SPOL1	4	1.40250000	0.64608426	0.73000000	1.79000000	0.32304218	5.61000000	0.417415	46.067
SPOL2	4	0.16750000	0.24540732	0.00000000	0.52000000	0.12270391	0.67000000	0.060225	146.512
SNELUT	6	0.01333333	0.07420692	-0.09000000	0.10000000	0.03029455	0.08000000	0.005507	555.552
TGS	7	63.40426571	145.33416372	3.00000000	404.00000000	56.06126355	478.63000000	22360.057129	216.235
TGS	5	188.20000000	81.4525075	125.00000000	320.00000000	36.41675111	941.00000000	6631.700000	43.271
COND	7	163.57142657	102.82324177	50.00000000	350.00000000	38.86353239	1145.00000000	10572.619048	52.561
PH	7	7.40000000	0.61913519	6.40000000	8.10000000	0.23401262	51.80000000	0.735333	8.267
TURB	7	17.92657143	16.87720897	3.00000000	50.00000000	6.40166526	125.50000000	286.667448	94.470
TOC	4	6.75000000	2.67226152	3.00000000	10.00000000	1.42614066	27.00000000	6.253000	42.552
TALIP	6	7.76750000	11.15413555	0.62500000	29.70000000	4.5650585	46.60500000	125.094777	143.786
TACM	6	0.91583333	0.77674599	0.43000000	2.52000000	0.32527019	5.47500000	0.634304	56.777
TPOL1	1	1.25000000	.	1.25000000	1.25000000	.	1.25000000	.	.
TPOL2	1	0.35000000	.	0.35000000	0.35000000	.	0.35000000	.	.
TPOL12	4	4.48500000	4.91300055	1.61000000	11.80000000	2.45650327	17.74000000	24.137553	109.543
TNELUT	6	0.54500000	1.15137744	-0.02000000	2.67000000	0.47004787	3.27000000	1.323670	211.261
EHYDRO	6	0.82666667	0.50345473	0.43000000	1.62000000	0.20553453	4.96000000	0.153467	60.902
PHYDRO	6	7.85566667	11.53333335	0.96000000	50.75000000	4.74726743	47.14503000	135.034387	142.570
THYDRO	6	6.68333333	11.95915059	1.37000000	32.12000000	4.82061609	52.16000000	142.921147	137.578
FHYDRO	6	0.61491017	0.12703203	0.42768421	0.72362382	0.05186561	3.2234610	0.616137	21.000
FEELUT	6	0.03090075	0.02672717	-0.00671141	0.66160723	0.01099297	0.1254045	0.000725	123.874
FALIP	6	0.48298227	0.18715661	0.20973154	0.67476469	0.07340637	2.6576876	0.053028	75.750
FARM	6	0.12192790	0.08250549	0.05371169	0.25671141	0.03368273	0.7315574	0.008807	87.267
TPOL	4	5.24350000	6.33533674	1.59000000	14.69000000	3.16766337	20.97000000	40.136472	130.246
FFOL	4	0.40419260	0.09735154	0.31315135	0.53355705	0.04967577	1.5167744	0.009871	14.530
TCGRS	4	2.73557761	0.55368168	1.9430179	3.19149736	0.27304064	10.9423164	0.519294	20.350
TCGEP	4	1.60491827	0.71141613	0.22871327	1.62307692	0.75579907	4.0196731	0.504116	70.794
TCGR	4	0.68553584	0.41454774	0.21217418	1.20000000	0.27727767	2.7421425	0.171832	60.471
PRATIO	10	1.42000000	1.20535241	0.20000000	3.40000000	0.38116730	14.20000000	1.452269	84.664
SRATIO	10	1.87000000	1.20374416	0.30000000	3.60000000	0.38065703	18.70000000	1.447000	84.371
TRATIO	10	1.57576675	1.21059998	0.20640817	3.50263152	0.38182533	15.7578675	1.4653552	76.225

APPENDIX C

LISTING OF POTW DATA AND SUMMARY STATISTICS

(See Table IV-1 for abbreviation key)



1SAS

14:13 FRIDAY, SEPTEMBER 27, 1985

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SEM	VARIANCE	C.V.
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STATION=EBDA -----

OIL_SOL	3	5.19333333	1.35208481	3.80000000	6.5000000	0.76062653	15.5800000	1.623133	26.035
OIL_PART	3	7.76333333	5.51302397	2.05000000	13.0400000	3.18294588	22.0900000	30.397433	74.871
OIL_T	3	12.55666667	6.29724014	7.31000000	19.5400000	3.63571329	37.8700000	39.655133	50.151
TSS	4	21.05500000	9.64379420	11.60000000	32.1000000	4.82159710	54.1200000	71.003767	45.603
TDS	4	709.00000000	81.35109696	615.00000000	805.0000000	40.67554548	2838.0000000	6618.000000	11.474
COND	4	587.50000000	170.17148214	350.00000000	1200.0000000	85.08574107	3950.0000000	23950.333333	17.233
PH	4	7.05000000	0.10801234	6.90000000	7.1500000	0.05400617	28.2000000	0.011667	1.552
TURB	4	21.00000000	1.62255216	18.00000000	23.0000000	0.61649658	84.0000000	2.000007	7.776
TOC	0	.	.	.	.	.	.	.	.

STATION=EEMUD -----

OIL_SOL	5	3.32300000	0.79080337	1.9800000	3.9900000	0.35345803	16.6400000	0.625173	22.742
OIL_PART	5	2.56800000	1.19207502	1.70000000	2.9580000	0.47284506	14.6400000	1.214570	25.148
OIL_T	5	5.59200000	1.53072316	3.7800000	7.4100000	0.67114780	29.5800000	1.251173	22.145
TSS	4	12.47750000	4.25642111	10.1000000	18.9100000	2.14221553	49.5900000	18.373471	24.246
TDS	4	817.50000000	148.35430555	718.0000000	1072.0000000	74.17715262	3870.0000000	22069.000000	16.167
COND	4	1137.50000000	265.75365502	1800.0000000	1603.0000000	171.576821266	5150.0000000	70825.000000	20.541
PH	4	6.49250000	0.21265170	6.3500000	6.5500000	0.10633063	25.4730000	0.045223	1.273
TURB	4	21.00000000	2.70801050	8.0000000	14.0000000	1.75400440	48.0000000	7.727777	22.567
TOC	0	.	.	.	.	.	.	.	.

STATION=MTVIEW -----

OIL_SOL	4	3.40250000	1.14683259	1.88000000	4.1300000	0.57341630	13.6100000	1.715125	33.706
OIL_PART	4	6.05500000	1.12920326	5.07000000	7.2000000	0.5646163	24.2200000	1.275100	16.647
OIL_T	4	9.45750000	2.20062630	6.93000000	11.4100000	1.10031340	37.5500000	4.642783	27.128
TSS	4	13.66250000	4.79065500	8.15000000	19.3000000	2.39542750	54.6500000	22.752197	33.066
TDS	4	594.50000000	55.81893119	512.0000000	950.0000000	27.40346560	3578.0000000	3459.666667	6.573
COND	4	1010.00000000	49.66554509	550.0000000	1070.0000000	24.83277404	4940.0000000	2466.666667	4.317
PH	4	6.51000000	0.13490733	6.2000000	7.1000000	0.06745769	27.5400000	0.018200	1.952
TURB	4	15.25000000	8.05708796	10.0000000	27.0000000	4.02354399	51.0000000	64.916557	52.373
TOC	0	.	.	.	.	.	.	.	.

1SAS

14:13 FRIDAY, SEPTEMBER 27, 1985

OBS STATION DATE OIL_SOL OIL_PART OIL_T TSS TDS COND PH TURB TOC

1 EBDA	JULY	3.60	7.02	19.62	26.02	673	1200	7.05	19	.
2 EBDA	APRIL	6.50	13.04	19.54	32.10	605	1050	6.50	23	.
3 EBDA	NOV	5.26	2.93	7.31	14.50	738	650	7.10	21	.
4 EBDA	OCT	.	.	11.80	815	850	7.15	21	.	.
5 EEMUD	JULY	3.42	5.99	7.41	18.71	1072	1500	6.75	17	.
6 EEMUD	JULY	3.60	7.50	6.55	.	.	.	.	.	.
7 EEMUD	APRIL	1.45	1.70	5.15	10.18	856	1150	6.75	8	.
8 EEMUD	NOV	1.73	1.60	1.78	10.10	710	1050	6.80	13	.
9 EEMUD	OCT	3.99	2.85	5.64	18.50	926	1400	6.47	14	.
10 MTVIEW	JULY	3.16	5.07	8.23	8.15	930	1020	6.85	10	.
11 MTVIEW	APRIL	4.36	6.85	11.21	15.80	750	1070	6.50	10	.
12 MTVIEW	NOV	1.65	5.10	6.75	12.50	916	1050	7.10	14	.
13 MTVIEW	OCT	4.21	7.20	11.41	15.50	812	950	6.51	17	.

3

